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Architects' perspectives on construction waste reduction by design

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Abstract

The construction, demolition and excavation waste arising in England was estimated at 91 million tonnes in 2003. The current thinking on construction waste minimisation is heavily focussed on several issues relating to physical construction waste and recycling guides. Indeed, much had been published on ways to improve on-site waste management and recycling activities but very few attempts made to address the effect of design practices on waste generation. However, there is a consensus in the literature that the architect has a decisive role to play in helping to reduce waste by focussing on designing out waste. This paper examines previous studies on architects' approach towards construction waste minimisation; and by means of a postal questionnaire, investigates: the origins of waste; waste minimisation design practices in the UK; and responsibilities and barriers within the UK architectural profession.

The findings reveal that waste management is not a priority in the design process. Additionally, the architects seemed to take the view that waste is mainly produced during site operations and rarely generated during the design stages; however, about one-third of construction waste could essentially arise from design decisions. Results also indicate that a number of constraints, namely: lack of interest from clients; attitudes towards waste minimisation; and training all act as disincentives to a proactive and sustainable implementation of waste reduction strategies during the design process.

1. Introduction

The construction industry plays a leading role in improving the quality of the built environment, but its activities also impact on the wider environment in a number of ways, including waste production. The construction, demolition and excavation waste arising in England alone was estimated at 91 million tonnes in 2003 (ODPM, 2004). As the rate of construction in the UK is set to increase, there is a pressing need to reduce waste at all stages of construction by considering the long-term impacts of design, build and waste management. However, the construction industry's culture and resistance to change are significant challenges to effective waste minimisation (Teo and Loosemore, 2001). There is a consensus in literature that a substantial amount of construction waste originates as a result of poor design (Innes, 2004; Chandrakanthi et al., 2002; Ekanayake and Ofori, 2000; Faniran and Caban, 1998; Bossink and Brouwers, 1996). The architect therefore has a decisive role to play in helping to reduce waste in construction at all levels by focussing on designing out waste (Greenwood, 2003; Coventry et al., 2001). In order to maximise their influence, architects need to understand the issues, constraints and opportunities related to waste prevention, and the practical means by which improvements can be achieved. By improving waste minimisation design practices, architects could realistically and successfully accelerate the pace of change. The aim of this study is to assess architects' views on the origins of design waste, current waste minimisation design practices in the United Kingdom (UK), and barriers to construction waste minimisation.

2. Methodology

A two-fold quantitative research approach was adopted for this study. First, a thorough literature review was conducted to: obtain insights into the waste minimisation

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debate in construction; discuss waste origins; and assess the role of architects in improving waste reduction through design. Secondly, a questionnaire was disseminated to the UK 100 top architectural practices, selected from The Architects' Journal The Architects' Journal (AJ Plus, 2005). The Architects' Journal ranking of architectural practices is based on the number of qualified architects within the firms. The UK's largest architectural practices were selected for this survey because of their adequate resources in place, which should potentially facilitate the planning, enforcement and implementation of waste minimisation design strategies in their projects. Additionally, partners and associates were targeted within the sampling frame, as they lead the decision-making process over the wider context of planning, design and implementation matters within their architectural practices. The survey was designed with six sections and a total of 22 questions that covered a number of topics (e.g., environmental certification status; sources of information in regard to waste minimisation; causes of waste; waste management responsibilities; waste minimisation design practices; and barriers and incentives). The questionnaire included a combination of rating scales, multiple-choice questions and open-ended questions. Responses were requested based on current or recently completed building design projects. At the end of each section, a space was provided for respondents to accommodate additional information with regard to the specific topic under investigation (i.e., causes of waste). Finally, an open-ended question was added at the end of the questionnaire to capture informants' views on other waste minimisation design issues that were not covered in the survey.

An important aspect of conducting a questionnaire survey is to ensure the largest possible return to enable meaningful data analysis (Fowler, 2002). As such, efforts were made to ensure high responses from respondents. These include: a personalised cover letter; a confidentiality statement to assure the respondents that any data provided would be held in strict confidence; printed questionnaires, using 120 mg A3 back-to-back paper; a self-addressed stamped envelope; telephone follow-ups of all non-respondents after 2 weeks from the initial mailing of questionnaires; and further telephone calls to re-contact all the remaining non-respondents. Additionally, a pilot study was carried out to test the questionnaire's ease and comprehension. Ten copies of the questionnaire were distributed to a range of multidisciplinary experts in building design and construction. The aim of the 'trial-run' exercise was to get feedback on the survey's structure, clarity of questions and instructions, flow of information, and length. As a result, revisions were made to improve the clarity and quality of the questions.

Of the 100 architectural practices surveyed, 19 questionnaires were received, after 2 weeks from the initial mailing. The telephone follow-ups increased the number to 37; and the final round of telephone calls to the remaining non-respondents resulted in a total of 46 replies. Of these, 40 questionnaires were usable, representing a response rate of 40%. The quantitative responses were analysed using the Statistical Package for Social Science (SPSS). Prior to data entry, all completed questionnaires were numbered, and questions and variables were coded. Once data input for the questionnaire's responses was completed, a process of data 'cleaning' was undertaken to ensure that the input entry was correctly executed. The following checks were carried out:

- double entry: entering the data twice and verifying discrepancies against the original questionnaires;
- frequency distribution: running SPSS frequency distribution and scanning for errors in values based on the original questionnaires; and
- data listing: printing out the values of all cases that have entered and verifying a random sample against the original questionnaires.

The analysis of the five-point Likert scale questions (from 1: lowest level to 5: highest level) used the technique of comparing means by 'One Sampling *t*-Test', while 'Crosstabulation' statistics were computed to identify potential correlations between variables. Finally, open-ended questions were tabulated manually.

3. Construction waste minimisation

The current and ongoing research in the field of construction waste management and minimisation can be broadly categorised into the following eleven clusters.

- Construction waste quantification and source evaluation (Faniran and Caban, 1998; Ekanayake and Ofori, 2000; Poon et al., 2004a,b).
- On-site construction waste sorting methods and techniques (Poon et al., 2001).
- Development of waste data collection models, including flows of wastes and waste management mapping, to help with the handling of on-site waste (Treloar et al., 2003; Shen et al., 2004).
- Development of on-site waste auditing and assessment tools (McGrath, 2001; Chen et al., 2002).
- Impact of legislation on waste management practices (Eikelboom et al., 2001).
- Improvements of on-site waste management practices (McDonald and Smithers, 1998).
- Reuse and recycle in construction (Emmanuel, 2004; Lawson et al., 2001).
- Benefits of waste minimisation (Rounce, 1998; Coventry et al., 2001).
- Waste minimisation manuals, including guides for designers (Coventry and Guthrie, 1998; Greenwood, 2003).
- Attitudes towards waste (Lingard et al., 2000; Teo and Loosemore, 2001; Sanders and Wynn, 2004).
- Comparative waste management studies (Chen et al., 2002).

Research reports, such as the work of Coventry et al. (2001), aim to promote awareness in the building construction industry about the benefits of waste minimisation, including cost savings, and environmental issues and use of recycled and reclaimed materials. The 'three Rs' principle of waste (reduction, re-use and recycle), otherwise known as the waste hierarchy, has been widely adopted. Similarly, the impact of legislation, particularly the Landfill Tax, and its effects on the behaviour and practices of the construction industry has resulted in a number of research studies. Additionally, tools, models and techniques have been developed to help handle and better manage on-site waste generation. While these tools facilitate auditing, assessment and benchmarking; waste source evaluation approaches do not offer long-term benefits, because they fail to address fundamental causes of waste. Furthermore, during the last few years many waste minimisation and recycling guides have been produced (e.g., Greenwood, 2003). These documents give broad guidance for architects to adopt a waste minimisation approach in their projects; however, the recommendations in these guides do not realistically relate waste to all parameters of the architects' environment, including the complex design and construction process and the supply chain. Additionally, they do not specifically identify waste-stream components in relation to their occurrence during the architectural design stages. Consequently, literature in the field deals with waste that has already been produced, but there is insufficient effort and no structured approach to address waste at source, i.e., 'design waste'. For the scope of this study, 'waste minimisation' is defined as "the reduction of waste at source, by understanding and changing processes to reduce and prevent waste" (Environment Agency, 2001). Similarly, 'design waste' is defined as "the waste arising from construction sites both by acts and/or omissions on the part of the designer, including opportunities to reduce waste lost by not using reclaimed materials" (Coventry and Guthrie, 1998).

4. Origins of design waste

Construction waste is effectively generated throughout the project from inception to completion with the pre-construction stage accounting for a considerable amount, as shown in Table 1.

It has been estimated that 33% of on-site waste is due to architects' failure to implement waste reduction measures during design stages (Innes, 2004). However, Keys et al. (2000) explained that the process of construction waste production through design is complex because buildings embody a diverse range of materials and products; and various project stakeholders, namely clients, contributed directly or indirectly to waste arising. However, there is a general consensus in literature that design changes (including variations) occurring whilst construction is in progress are key origins of construction waste production (Bossink and Brouwers, 1996; Faniran and Caban, 1998). The main drivers for design variations during construction are: last minute client requirements (resulting in rework); designers' lack of experience in evaluating construction methods and the sequence of construction operation (leading to detailing errors that require alteration or abortion of completed works);

Table 1
Origins and causes of construction waste (compiled from the main sources within the literature)

Origins of waste	Causes of waste
Contractual	• Errors in contract documents • Contract documents incomplete at commencement of construction
Design	• Design changes • Design and detailing complexity • Design and construction detail errors • Unclear/unsuitable specification • Poor coordination and communication (late information, last minute client requirements, slow drawing revision and distribution)
Procurement	• Ordering errors (i.e., ordering items not in compliance with specification) • Over allowances (i.e., difficulties to order small quantities) • Supplier errors
Transportation	• Damage during transportation • Difficulties for delivery vehicles accessing construction sites • Insufficient protection during unloading • Inefficient methods of unloading
On-site Management and planning	• Lack of on-site waste management plans • Improper planning for required quantities • Delays in passing information on types and sizes of materials and components to be used • Lack of on-site material control • Lack of supervision
Material storage	• Inappropriate site storage space leading to damage or deterioration • Improper storing methods • Materials stored far away from point of application
Material handling	• Materials supplied in loose form • On-site transportation methods from storage to the point of application • Inadequate material handling
Site operation	• Accidents due to negligence • Unused materials and products • Equipment malfunction • Poor craftsmanship • Use of wrong materials resulting in their disposal • Time pressure • Poor work ethics
Residual	• Waste from application processes (i.e., over-preparation of mortar) • Off-cuts from cutting materials to length • Waste from cutting uneconomical shapes • Packaging
Other	• Weather • Vandalism • Theft

increasing design complexity (producing off-cuts); lack of design information (leading to assumptions made by contractors and sub-contractors, which result in over-ordering of materials); unforeseen ground conditions (leading to soil waste); and long project durations (allowing the design to be modified to suit changes in the market, research or legislation) (Poon et al., 2004a; Ekanayake and Ofori, 2000). Additionally, Keys et al. (2000) reported that waste generated during the design process is mainly due to: 'poor communication' leading to mistakes and errors; and 'overlapping of design and construction', which further complicate the management of the design process and moves waste prevention issues to the bottom of the priority list. Chandrakanthi et al. (2002) went further by stating that a lack of knowledge about construction techniques during design activities can also result in waste being produced.

5. Improving construction waste minimisation through design

An increasing body of literature, notably that produced by: Coventry and Guthrie (1998), Greenwood (2003), Poon et al. (2004a), and Baldwin et al. (2006), has demonstrated that the architect has an important part to play in construction waste minimisation and reduction. As such, Coventry and Guthrie (1998) suggested three key roles that architects should play, namely: giving advice to clients; initiating waste reduction at a project level; and improving design practices generally. The following could be considered, within waste minimisation context, during the RIBA (Royal Institute of British Architects) Plan of Work Stages (Phillips, 2006). The RIBA Plan of Work is recognised throughout the United Kingdom construction industry as a design and management framework for running a project from appraising the client's requirements through to post-construction (Table 2).

Table 2
RIBA plan of work stages (after Phillips, 2006)

RIBA plan of work stages	Description
A (appraisal)	Identification of client's requirements and possible constraints on development; and studies to enable the client to decide whether or not to proceed and select a procurement route
B (strategic briefing)	Preparation of strategic brief by or on behalf the client confirming key requirements and constraints; and identification of procedures, organisational structure, and consultants
C (outline proposals)	Development of the strategic brief into a full project brief; preparation of outline proposals and estimate cost; and review procurement route
D (detailed proposals)	Complete development of project brief; preparation of detailed proposals; and application for full development control approval
E (final proposals)	Preparation of final proposals sufficient for coordination of all project components and elements
F (production information)	Preparation of production information in sufficient detail to enable tenders to be obtained; and application for statutory approvals
G (tender documentation)	Preparation and collation of tender documentation in sufficient detail to enable tenders to be obtained
H (tender action)	Identification and evaluation of potential contractors and/or specialists; and obtaining and appraising tenders, and submission of recommendations to the client
J (mobilisation)	Letting the building contract; appointing the contractor; issuing production information to the appointed contractor; and arranging site hand-over to the contractor
K (construction to practical completion)	Administration of the building contract up and including practical completion
L (after practical completion)	Administration of the building contract after practical completion; and making final inspections for setting the final account

- Giving advice to clients by briefing them on the impact of waste production and highlighting benefits including cost savings. Indeed, many clients are under informed about the severity of construction waste (Dainty and Brooke, 2004). Waste minimisation could be instigated, in partnership with clients and consultants, by analysing the benefits of waste reduction at Stage A ('Appraisal: determine the level of detail the client requires to make the decision to proceed') during the initial brief evaluation and value management or cost benefit studies. In line with this, Innes (2004) reported that waste minimisation case studies in construction have shown savings of 3% of build costs without significant investment outlay.
- Initiating waste reduction at a project level by addressing issues such as design life; undertaking waste reviews at key design stages; waste reduction opportunities; use of reclaimed material; use of prefabricated and off-site preparation of materials; and use of standardised components. These issues could be: embedded in Stage B ('Strategic Briefing: carry out studies, i.e., user requirement, site conditions, planning and cost, which will allow the outline design to be developed'); and further investigated during the development of Stage C ('Outline Proposals: prepare alternative designs and provide information for cost planning'), where waste minimisation may be assigned a high weighting criterion to evaluate and select the preferred design option.
- Improving design practices by addressing the key causes of design waste. According to Coventry and Guthrie (1998), design waste should be tackled by addressing various issues during the design process and include better coordination at project level to eliminate design and

detailing amendments in order to avoid abortive work during site operations; design for deconstruction; planning to minimise wastage through off-cuts; the use of reclaimed building materials; and appropriate specification of design performance and products and improve design. The RIBA Plan of Work Stage D ('Detailed proposals: develop a firm design solution, prepare a cost estimate, and submit application for full planning permission') and Stage E ('Final Proposals: obtain final decision on all matters related to design, specification, construction detailing and cost') provide an opportunity to implement waste reduction measures by design, and improve communication aiming at freezing the design at the end of Stage D to eliminate late changes during site operations ('Stage K: follow plans and control site activities through to practical completion of the project'). Similarly, physical waste could be minimised during the preparation of Stage F ('Production Information: prepare final drawings, schedules, and specifications') through accurate detailing and clear specification, which takes into consideration life cycle assessment of materials.

However, questions remain as to whether the architectural profession is culturally, strategically and logistically prepared for proactive supply chain partnering to engender significant improvements in waste minimisation performance. Additionally, the challenge to architects is how to embed waste reduction strategies within conventional design processes which require a clear understanding of design waste origins.

6. Potential strategies to reduce design waste

The extant literature reveals various approaches, guidelines and strategies to reduce design waste. These broadly cover four major axes of the design process including contract language: design issues and construction techniques; building materials specification; and education.

First, contract and contractual agreement stages could play a decisive role in reducing waste through incorporating waste minimisation activities by means of the use of specifically oriented contract tender clauses (CRiBE, 1999), for example, Dainty and Brooke (2004) suggested using contractual clauses to penalise poor waste performance. The same recommendation was put forward by Greenwood (2003, p. 4), who went further, calling for a fully integrated waste minimisation system at the contractual stage that "should identify and communicate the responsibilities for waste minimisation between all project stakeholders".

Secondly, literature reveals that substantial amount of waste is directly related to late changes during site operations. Coventry et al. (2001) pointed out that these amendments change the type or quantity of building materials required at later stages. Furthermore, Hylands (2004) identified standardisation of design as a construction method to improve buildability and reduce the quantity of off-cuts. Gibb (2001) argued that standardisation and prefabrication of both building layouts and components result in less waste. Similarly, Baldwin et al. (2006) argued that precasting and prefabrication offer significant opportunities to reduce waste. Dainty and Brooke (2004) went further by reporting that the use of off-site prefabrication leads to better control of waste and damage. However, Gibb (2001) acknowledged that there has not been much research to date on the relationship between prefabrication and sustainability in general and waste minimisation in particular.

Thirdly, waste can be reduced in a number of ways by specifying the use of efficient framing techniques, standard size supplies, and prefabricated components into the design. Indeed, designs that require more material than necessary, as a result over-specification will generate waste (Greenwood, 2003). Additionally, architects can influence reusability and recyclability of building materials through the choice of the structural system, component types and their connections, and through the choice of materials (Sarja, 2002). However, architects are often reluctant to specify recycled materials in their projects, mainly due to: concerns related to their properties (Sassi, 2004); guaranteed standards uncertainties; and lack of knowledge (Coventry et al., 2001). Research studies into construction recycling have been conducted more recently. Among these was the publication of a guide to specification by the building research establishment (BRE), which assesses the relative environmental performance of over 250 materials and components (Anderson et al., 2002). The "Green Guide" contains a wide range of alternative specifications for walls, floor systems, floor finishes, roofs, windows, doors, ceilings, paints, insulation and landscaping. The performance of each specification is measured against a range of environmental impacts, including climate change, toxicity, fossil fuel and ozone depletion, levels of emissions and pollutants and mineral and water extraction.

Finally, education programmes could potentially help the client and other stakeholders appreciate waste minimisation benefits and the strategies to be employed in the project to achieve set targets. This will "ensure that the client understands the need for process and attitudinal change and that would encourage them to influence waste conscious design and construction practices from the inception of projects" (Dainty and Brooke, 2004, p. 24). However, the flow of information and dissemination of best practice to reduce design waste requires commitment and effective consultation and communication involving all project stakeholders.

The above guidelines could ensure that architects take the lead in educating their clients to recognise waste minimisation benefits and adopt waste reduction strategies in their projects. However, these are broad design guidelines without a comprehensible and focussed methodology to implement and sustain them. What architects need, which literature did not identify, is a clear and comprehensive tool to assist them in incorporating waste minimisation strategies during all stages of the design process. This paper is part of a research project that aims to develop a method of facilitating and sustaining the integration of waste minimisation within building design. To identify waste minimisation design practices within the UK architectural profession, two distinct sets of research activities were undertaken. These are described in the next section.

7. Survey findings

7.1. ISO 14001 certification and waste minimisation sources of information

Respondents were asked about their companies' environmental accreditation status. Only 17% of architectural practices said they held ISO 14001 certificates (ISO, 1996) and 25% were in the process of being accredited. Insights into the respondents' waste minimisation knowledge base are presented in Fig. 1, which indicates that only 14% attended training courses, while the overwhelming majority relied on other sources of information, namely, personal research and professional magazines to acquire relevant knowledge regarding construction waste issues.

7.2. Waste minimisation responsibilities

Informants' responses in regard to waste management responsibilities have been summarised in Fig. 2, which shows that few attempts were made in terms of waste minimisation planning, guidance and implementation. Indeed, 33% of respondents acknowledged that they never assumed any waste minimisation responsibilities in their projects, and 85% did not analyse potential waste that may arise during the design process, while only 2% organised waste management meetings.

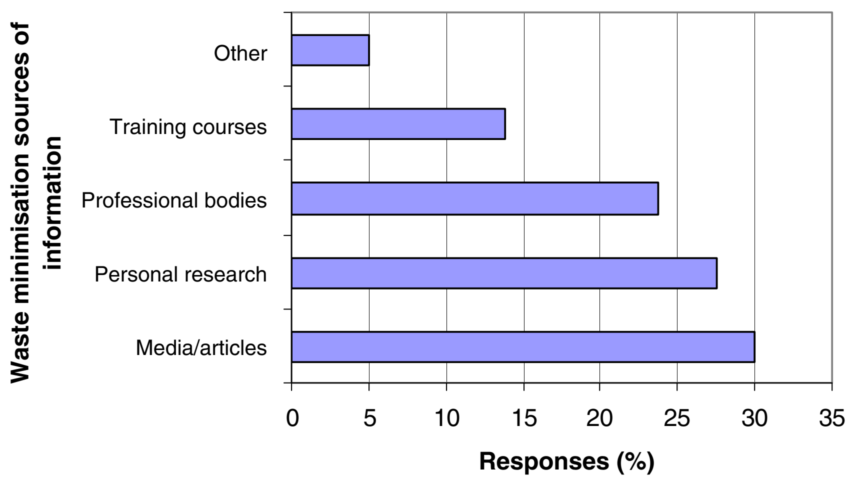

Fig. 1. Waste minimisation: sources of information used by architects (respondents' views).

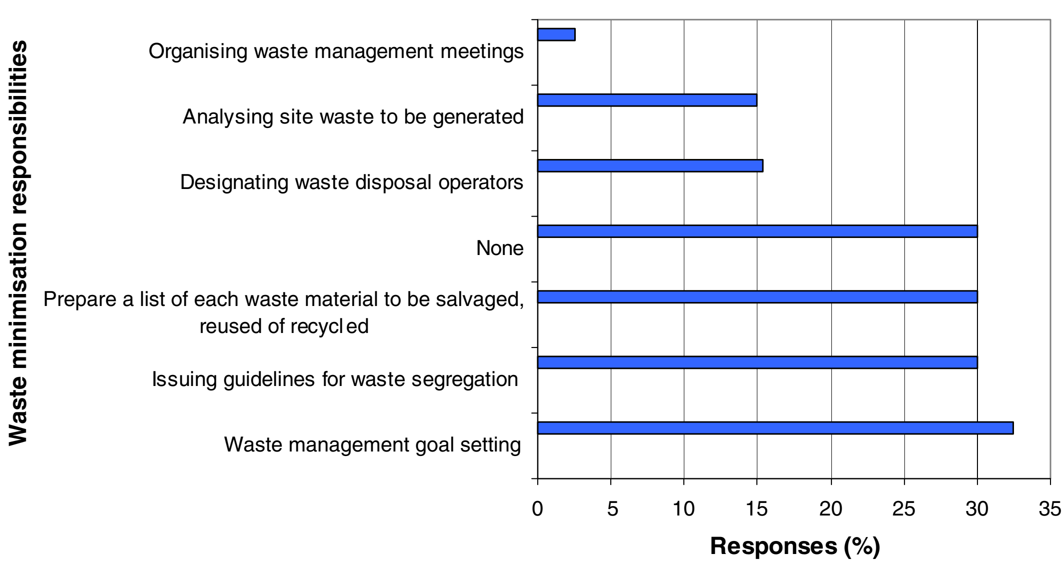

Fig. 2. Waste minimisation responsibilities (respondents' views).

Table 3
Causes of construction waste during design stages (respondents' views)

Causes of waste during design	Architects responses						
	Percentage					Mean ranking	Rating
	1	2	3	4	5		
Last minute changes due to client's requirements	7.5	0.0	17.5	35.0	40.0	4.00	1
Design changes	10.0	5.0	12.5	45.0	27.5	3.75	2
Detailing errors	12.5	17.5	30.0	25.0	15.0	3.13	3
Unclear specification	15.0	22.5	40.0	15.0	7.5	2.78	4
Lack of information on drawings	20.0	22.5	32.5	22.5	2.5	2.65	5
Delays due to drawing revision and distribution	12.5	30.0	40.0	17.5	0.0	2.63	6

1. Not a waste cause; 2. Insignificant waste cause; 3. Minor waste cause; 4. Significant waste cause; 5. Major waste cause waste cause.

Conversely, more than 32% of informants claimed that they implemented waste management goal setting, and 30% prepared a list of each waste material to be salvaged, reused or recycled.

7.3. Causes of design waste

The questionnaire gave each respondent an opportunity to rate 12 variables that contributed to construction waste during design stages and site operations, on a scale from 1 (not a waste cause) to 5 (major waste cause); the findings are shown in Tables 3 and 4.

Table 3 reveals that 'last minute changes by client' was accorded the highest attribute of waste during design stages. Additionally, architects graded 'design changes' as the second highest mean importance rating. However, only 2.5% of responding architects were of the opinion that 'lack of information on drawings' was a major cause of design waste, while just 18% reported that 'delays due to drawing revision and distribution' often led to waste generation. Respondents were asked to list other causes of waste during the design stages. There was a shared view that 'not designing to minimise waste in mind' and 'not designing for standardisation and to unit sizes' are major contributors to waste during the early stages of design. Furthermore, they identified other influencing factors namely: no consultation process; incorrect and over specification; and time pressure.

Table 4 shows that 'unused materials and products' and 'off-cuts' were placed at the top of causes of waste during site operations, followed by 'delays in forwarding information on sizes of materials to be used' and 'waste from application processes'. When asked to list other causes of waste during the construction stage, informants claimed that: contractors' lack of forward planning, and poor reading and interpretation of specification and construction details; and design changes have had serious impacts on on-site waste production.

Table 4
Causes of construction waste during site operations (respondents' views)

Causes of waste during site operations	Responses	
	Mean rating	Ranking
Unused materials and products	4.30	1
Off-cuts from cutting materials	4.15	2
Waste from application processes	3.80	3
Improper storing space and methods	3.63	4
Weather conditions	3.23	5
Delays in forwarding information on sizes of materials to be used	2.88	6

7.4. Design waste during the RIBA plan of work stages

Respondents were asked to rate potential waste production throughout the RIBA Plan of Work Stages (see Table 2) using the five-point Likert scale; where 1 indicates 'no waste' and 5 indicates 'major waste'. Table 5 shows that more than 87% of responding architects opined that significant to major waste generation occurred during site operations (Stage K). They claimed that: insignificant waste occurred during Outline Proposals (Stage C); minor waste is produced during Detailed and Final Proposals (Stages D and E); and slightly higher waste is produced during Production Information (Stage F). The manually tabulated architects' responses regarding origins and causes of design waste reveal that the major concern of architects lies in the lack of understanding of what creates waste. Additionally, there is a common view among respondents that poor decision-making during early design stages can have major implications on-site, as one respondent stated: "poor design is a principal driver of waste". Another informant went further by stating that "fundamentally flawed designs at Appraisal stage may be more wasteful than alternative concepts".

7.5. Waste minimisation design strategies

Informants were asked to rate from 1 (never been used) to 5 (used in all projects) the extent of integration of design waste strategies within their projects. Table 6 shows that very few attempts were made to design in waste reduction strategies. Additionally, the results revealed that none of the responding architects conducted a 'feasibility study of waste estimation' as a matter of course in all their projects

Table 5
Potential waste generation during the RIBA plan of work stages (respondents' views)

RIBA plan of work stages	Architects' responses					
	Percentage					Mean rating
	1	2	3	4	5	
Stage A (appraisal)	45.0	25.0	12.5	12.5	5.0	2.08
Stage B (strategic briefing)	30.0	20.0	22.5	17.5	10.0	2.58
Stage C (outline proposals)	22.5	25.0	25.0	25.0	2.5	2.60
Stage D (detailed proposals)	15.0	12.5	37.5	30.0	5.0	2.98
Stage E (final proposals)	15.0	7.5	47.5	22.5	7.5	3.00
Stage F (production information)	7.5	17.5	35.0	35.0	5.0	3.13
Stage G (tender documentation)	15.0	22.5	30.0	27.5	5.0	2.85
Stage H (tender action)	30.0	10.0	27.5	27.5	5.0	2.68
Stage J (mobilisation)	22.5	17.5	32.5	17.5	10.0	2.75
Stage K (construction to practical completion)	2.5	5.0	5.0	30.0	57.5	4.35

1. No waste generation; 2. Insignificant waste; 3. Minor waste; 4. Significant waste; 5. Major waste generation.

Table 6
Extent of implementation rating of waste minimisation strategies (respondents' views)

Waste minimisation design strategies	Architects' responses					
	Percentage					Mean rating
	1	2	3	4	5	
Feasibility study of waste estimation	45.0	25.0	22.5	7.5	0.0	1.93
Designing for deconstruction	30.0	32.5	27.5	7.5	2.5	2.20
Use of standard dimensions and units	5.0	20.0	27.5	32.5	15.0	3.33
Use of prefabricated units	2.5	20.0	42.5	27.5	7.5	3.18
Specifying reclaimed/recycled materials	5.0	32.5	35.0	27.5	0.0	2.85
Use of standard materials to avoid Cutting	5.0	15.0	40.0	35.0	5.0	3.20
Avoidance of late variations in design	15.0	12.5	27.5	37.5	7.5	3.10
Guidance for hazardous waste Management	18.5	30.5	21.0	20.0	10.0	2.83

1. Never been used; 2. Rarely used; 3. Used in some projects; 4. Used in most projects; 5. Used in all project.

and only about 2% designed for deconstruction as a common practice. However, more than a third of the surveyed architects claimed that they used, whenever possible, standard dimensions and prefabricated units to avoid on-site materials cutting.

Responses to the level of implementing waste reduction strategies during the RIBA Plan of Works Stages have been presented in Table 7, which indicates that more than 82% of architects never, rarely or sometimes applied waste reduction strategies during Appraisal; Strategic Briefing; and Outline Proposals (Stages A–C). Additionally; 8% reported that waste reduction measures were implemented in all projects during Final Proposals (Stage E) and Production Information (Stage F).

Table 7
Extent of implementation of waste minimisation strategies during the RIBA plan of work stages (respondents' views)

Waste minimisation design strategies	Architects' responses					
	Percentage					Mean rating
	1	2	3	4	5	
Stage A (appraisal)	35.0	35.0	17.5	7.5	5.0	2.13
Stage B (strategic briefing)	25.0	32.5	25.0	10.0	7.5	2.42
Stage C (outline proposals)	10.0	30.0	42.5	12.5	5.0	2.73
Stage D (detailed proposals)	5.0	25.0	30.0	32.5	7.5	3.13
Stage E (final proposals)	2.5	15.0	35.0	40.0	7.5	3.35
Stage F (production information)	5.0	12.5	37.5	32.5	12.5	3.35
Stage G (tender documentation)	7.5	22.5	35.0	25.0	10.0	3.18
Stage H (tender action)	20.0	25.0	27.5	22.5	5.0	2.78
Stage J (mobilisation)	27.5	32.5	22.5	12.5	5.0	2.48
Stage K (construction to practical completion)	10.0	27.5	32.5	25.0	5.0	2.88

1. Never been used; 2. Rarely used; 3. Used in some projects'; 4. Used in most projects'; 5. Used in all projects.

Table 8
Waste minimisation barriers (respondents' views)

Barriers	Responses	
	Mean rating	Ranking
Lack of interest from clients	3.88	1
Waste accepted as inevitable	3.83	2
Poorly defined individual responsibilities	3.80	3
Lack of training	3.70	4

Table 9
Waste minimisation incentives (respondents' views)

Barriers	Responses	
	Mean rating	Ranking
Legislation	4.55	1
Financial rewards	4.55	1
Waste management policy in place	3.93	2
Training	3.90	3

7.6. Design waste minimisation barriers and incentives

Results of barriers and incentives to waste minimisation practices are summarised in Tables 5 and 6. Although there is a broad equal rating of constraints, responding architects ranked 'lack of interest from clients' as the major barrier that impedes design waste reduction, as shown in Table 8. Additionally, 'waste accepted as inevitable' and 'poor defined individual responsibilities' were also reported as the next most significant hindrances to waste reduction; followed closely by 'lack of training'.

Conversely, informants established a clear hierarchy of incentives, as shown in Table 9, by equally ranking 'legislation' and 'financial rewards' as the two key incentives that could drive waste reduction during the design process. They also acknowledged that 'waste management policy in place' and 'training' are important factors in assisting architects to design out waste.

8. Discussion

Having targeted the top 100 UK architectural firms as the survey's sampling frame, efforts were made to ensure the highest possible response rate by addressing the disadvantages and limitations of a typical postal questionnaire. These included: designing the questionnaire to avoid ambiguity and asking questions beyond the respondents' capabilities; carrying out a pilot survey to test its clarity and comprehension; and identifying the most suitable people by name and job title within the surveyed organisations to provide the data required for the research. That said; it may be the case that a larger number of respondents may have produced slightly different results. Nevertheless, the findings of the survey clearly indicate that waste minimisation is not a priority during the design process, reinforcing research by Poon et al. (2004a). Additionally, changing current attitudes towards waste minimisation and understanding the underlying origins and causes of design waste were identified as significant hurdles that architects would need to overcome and comprehend prior to adopting and sustaining waste reduction design activities in their projects.

It is interesting to note that client activities could be a major origin of design waste through variation orders. Indeed design changes to meet client's changing requirements and preferences were ranked at the top of design waste causes. This was echoed by the findings of Ekanayake and Ofori (2000) and Faniran and Caban (1998). Additionally, detailing errors were identified as significant origins of waste during the design process. Similar results were provided by Faniran and Caban (1998) and Graham and Smithers (1996).

In terms of waste minimisation responsibilities, a third of the respondents reported that they used waste management goal setting, and 30% prepared a list of waste materials to be salvaged, reused or recycled. However, 45% concurred that they never conducted a feasibility study of waste estimation, which appears rather contradictory.

From a strategic point of view, few architectural practices have actively pursued ISO 14001 certification (ISO, 1996). However, no correlation was established between environmental accreditation and effective waste minimisation design practices. Indeed, 95% of ISO 14001 certified respondents reported that they never conducted a waste minimisation feasibility study in their projects. The extant literature failed to identify the impact of environmental accreditation on architects' waste reduction practices. Additionally, very few responding architects attended any relevant courses. This would suggest that waste minimisation training is currently not a priority in architectural practices' Continuing Professional Development (CPD) agenda.

Respondents considered that waste arising during Appraisal (RIBA Plan of Work Stage A) was insignificant; therefore, no design waste reduction measures were initiated, as shown in Fig. 3. It is interesting to note fairly consistent overlaps of 'insignificant waste production' and 'relatively low implementation of design waste reduction' during Strategic Briefing; Outline, Detailed, and Final Proposals; Production Information; Tender Documentation and Action; and Mobilisation (Stages B–J). However, a diverging trend becomes apparent during Construction to Completion (Stage K). This would suggest that architects considered that most construction waste occurs during site operations and is rarely generated during design stages, directly or indirectly. This perception is a denial acknowledged by Innes (2004), Ekanayake and Ofori (2000), and Faniran and Caban (1998), whose findings reveal the design process contributes significantly to construction waste production.

Notwithstanding that current architects' practices fail to make considerable inroads to curb waste production through design, many respondents concurred that waste reduction must be addressed at the source and be a

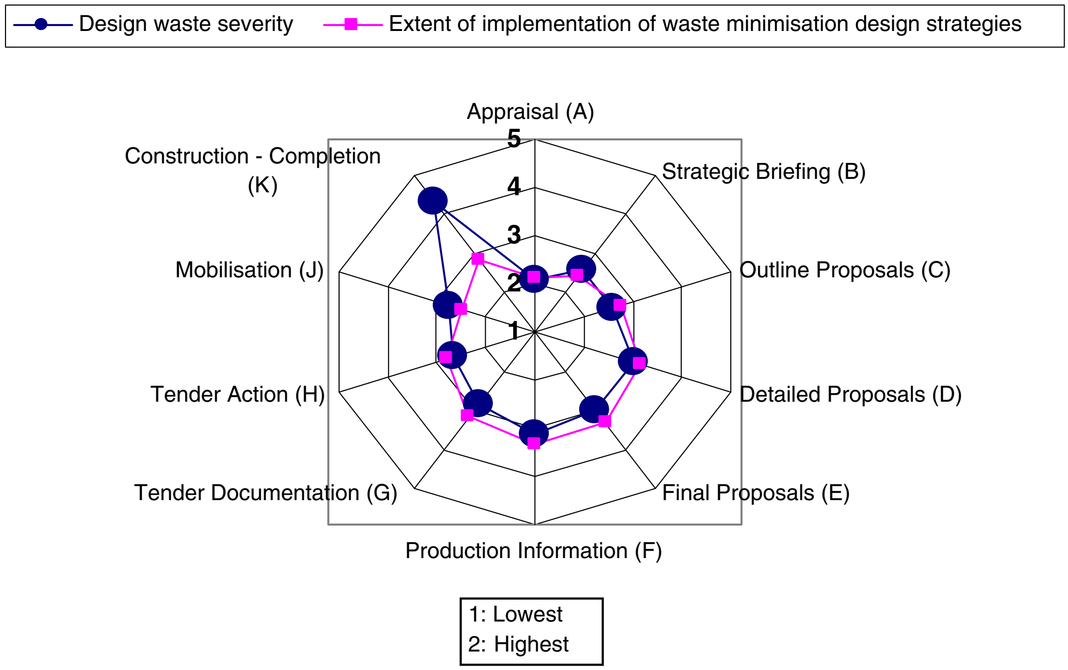

Fig. 3. Design waste severity versus extent of implementation of waste minimisation design strategies during the RIBA plan of work stages (respondents' views).

consideration at the concept stages. However, most of them acknowledged that designing out waste is not being implemented at present; as one respondent put it: "waste reduction is rarely considered during daily life in an architect's office". However, respondents reported that lack of interest from clients and 'waste accepted as inevitable' were their major concerns. On the other hand, there was consensus among informants that financial rewards and legislation are by far the key incentives to drive waste minimisation. Additionally, there was a call for rewarding versus penalising project stakeholders for their waste minimisation performance. This is supported by Chen et al. (2002) who reported that rewarding and penalising methods in regard to on-site material handling have been effectively used on construction sites through the use of special motivational and financial incentive programmes. However, the literature did not identify financial incentive schemes for waste minimisation performance at organisational and project levels.

Training was seen by the survey's participants as a catalyst for a change in the design culture and practices. However, architects argued that widely and easily accessible sources of information are necessary. One respondent commented: "I have seen very little information on training offered in this field. We would probably make use of it far more if readily available, accessible and inexpensive courses were on offer to architectural practices". The cross tabulation results of implementing waste minimisation strategies during the RIBA Plan of Work Stages versus training established a strong correlation between staff development courses and designing out waste practices. Indeed, the 79% of architects who were not provided with training hardly ever conducted a feasibility study of waste estimation in their projects. In line with this, Wong and Yip (2004), who conducted a multi-disciplinary survey involving architects, contractors and others, reported that only 22% attended construction waste related courses. They went further by arguing that appropriate waste minimisation training could raise project stakeholders' level of understanding "from 'unaware' through 'aware but not active' to 'aware and active' in the near future". However, there remains a gap in the literature regarding relationships between relevant architects' training programmes and successful implementation of design waste minimisation strategies in their projects.

The results of this survey indicate that architects' lack of engagement with designing out waste may be due to two reasons: a lack of understanding of what create design waste; and the assumption that waste minimisation is the contractor's responsibility.

9. Conclusions

The aim of this paper was to review construction waste through design; evaluate design waste minimisation practices within the largest UK architectural practices; and assess barriers that impede architects to design out waste. The findings revealed that most responding architects seemed reluctant to adopt waste design minimisation strategies on their projects. Additionally, holding environmental accreditation appeared to have no serious impact on design waste minimisation performance. Although respondents agreed that waste is a significant concern in construction, they shared the view that waste minimisation is often a low priority in the strategic planning and design activities of projects. Informants claimed that waste is predominantly produced during on-site activities (RIBA Stage K) and rarely generated during design stages (Stages C–F). This was compounded by the perception that waste is produced as a consequence of contractor's poor site planning, misinterpretation of architects' drawings and specification, and on-site logistical and operational activities. Nonetheless, architects conveyed their willingness to work with consultants and contractors to design out waste if incentivised by clients, particularly if they gained an enhanced fee for waste minimisation feasibility and implementation studies. It is interesting to note that minimising waste is considered as an ad hoc activity, not part of the core activities of the building design process. On the other hand, architects believed that there are a number of obstacles to designing out waste; namely perception of waste, unknown root causes of design waste, clients' requirements, and poorly defined responsibilities. Legislation and financial rewards were seen as the major incentives that could have a major impact on design waste reduction practices. This would suggest that increased fiscal measures and the introduction of systems of waste minimisation performance rewards rather than fines would have more effects on waste minimisation practices than voluntary approaches. Additionally, by acknowledging the need to understand the underlying causes of waste, architects recognised that training is a pressing issue.

Moving forward with waste minimisation in construction requires a thorough source evaluation of design waste, which should set out to influence a change to a waste reduction design paradigm. As such, the next step of this research will focus on root causes of design waste throughout the project life cycle through the development of a complete design waste mapping process. Hence a series of interviews with architects and contractors are in progress to identify potential creation of design waste across the RIBA Plan of work Stages.

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