The Recycled Building Project

Mark Gorgolewski, Ph.D.

ABSTRACT

The use of construction materials that are either recyclable or contain a high proportion of recycled material can lead to lower environmental impacts and a reduction of material in a landfill. However, the practical and economic aspects of using these construction materials are not properly understood within the construction industry.

This paper presents the results of a study carried out in the United Kingdom. The study appraised the economic feasibility and associated environmental benefits of using recycled and recyclable materials in construction. The aim was to measure the environmental impacts and financial costs of specifying a variety of recycled materials. The data were then used to raise awareness among designers, material producers, and other parties involved in construction of the opportunities, costs, and benefits offered by the use of such materials.

The work involved carrying out quantified comparisons of the cost and environmental impacts of using construction materials that are recyclable or contain a high proportion of recycled material. The analysis uses the functional units of a square meter of wall or roof element to provide comparative data of alternative cladding systems. The data are then aggregated into an assessment of a typical medium-rise commercial building.

The assessment considers the issues of cost, greenhouse gas emissions, energy use, and materials resource use for various materials used in the main components of the building, focusing on claddings, roofing, and foundations. Comparisons are made between conventional building specifications—those that maximize recycling potential and those that aim to minimize costs. The implications for environmental criteria and cost are assessed.

INTRODUCTION

Much of the environmental impact of buildings is associated with consumption of resources and generation of waste. The construction industry in the U.K. consumes over 350 million tonnes of a wide range of materials each year (about 6 tonnes per person per year). Over 90% of the non-energy minerals extracted in Great Britain are used to supply the construction industry with material (Figure 1). Construction generates about 70 million tonnes of waste (over 50% of all waste delivered to landfills), much of which is potentially recyclable. To provide a stimulus to reducing waste, the U.K. government introduced a landfill tax in 1996 on waste deposited in landfill sites. The government has recently considerably increased the rate at which this tax is levied. A tax on primary aggregates is due to be implemented in April 2002 to stimulate the use of recycled aggregates and waste materials as substitutes for primary aggregates. In other European countries, such as the Netherlands, most construction waste must be recycled. Effective waste management and efficient use of resources are, therefore, of growing significance for the construction industry.

The use of recycled materials and reused components in construction can lead to lower environmental impacts and a reduction in material disposed to a landfill. However, the practical, environmental, and economic aspects of using these construction materials are often not properly understood

Mark Gorgolewski is a principal architect at the Steel Construction Institute, Ascot, Berks, UK.

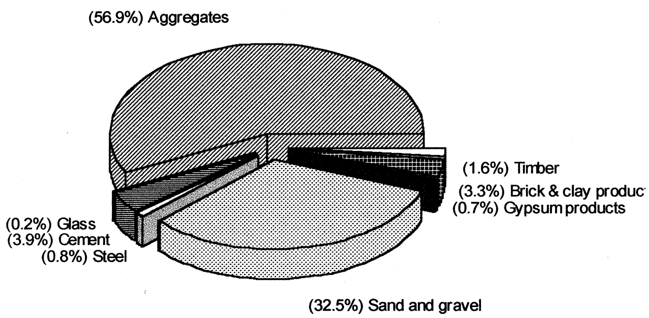

Figure 1 *The proportion (by mass) of materials used by the U.K. construction industry.*

within the construction industry. This project aims to quantify these aspects and thereby raise understanding and awareness among designers, materials producers, and other parties involved in construction of the opportunities and benefits offered by the use of recycled materials.

The objective of this project was to evaluate the cost and environmental impacts of reusing construction products or using products that contain a high proportion of recycled or waste material. The project provides a quantitative environmental and cost assessment of a typical office building with various primary and recycled specifications. The environmental impacts, in terms of embodied energy and greenhouse gas emissions, and the financial cost implications of the changes in specification are assessed. It was originally intended to include a quantitative assessment of resource consumption and waste generation; however, there was found to be a lack of data for these environmental burdens, particularly for recycled materials.

By quantifying and interpreting the environmental and financial impacts of various specifications, the project aims to raise understanding and awareness about the use of recycled materials. The conclusions derived from these assessments, together with general information about recycling and reuse collected during the project, are used to provide practical guidance for designers, contractors, and others involved in construction on the opportunities and benefits offered by the use of such materials.

METHODOLOGY

The project was undertaken in the following three phases.

Phase 1

Phase one involved the collection of cost and environmental data (embodied energy and greenhouse gas emissions) for:

- Conventional materials such as timber, primary concrete, and new bricks
- Recycled materials such as cellulose insulation, steel, and glass wool
- Reused components such as second-hand bricks, used roof slates, and steel piles extracted from a previous site

Data were collected from a variety of sources, including BRE (1999), IISI (1999), product manufacturers, and Ecobillan (1999). A methodology was developed for calculating environmental and cost data for reused components where little information currently exists (SCI 2000).

Phase 2

The second phase of the work involved calculating the embodied energy and greenhouse gas emissions and financial costs for a range of construction specifications for walls and roofs. This required the use of the environmental and cost data assembled as described above.

For this assessment, a square meter of opaque wall or roof element was chosen as the "functional unit" for analysis. A series of specifications for the external wall and the roof were developed. The first step was to choose a typical conventional specification with traditional primary materials. The environmental burdens and costs for a square meter of the element were calculated. The specifications were altered a step at a time by replacing a primary material element with a recycled or reused material one. For each amended specification, the cost and environmental impacts were calculated. The results for alternative wall specifications are presented in Table 1. Eventually a specification was reached that maximized the use of recycled/reused materials. In this way, the environmental impacts and cost implications of using recycled materials can be assessed.

Figure 2 compares the greenhouse gas emissions and costs per m^2 of the various wall specifications. This indicates that the very environmentally friendly wall specifications, such as options 7 and 20, are among the most expensive options. However, other wall specifications, such as 5, 6, 14, and 17, perform almost as well environmentally and at a reasonable cost. Nevertheless, there is a significant variation in greenhouse gas emissions between options that have similar costs. Thus, option 18 has a lower cost and better environmental performance than options 8, 9, or 10, and this demonstrates that a specifier looking to the lower cost options can significantly reduce greenhouse gas emissions by careful choice. Similarly, significant cost savings can be achieved without necessarily damaging the environment. Thus, option 6 costs only £115 per m^2 compared to £162 per m^2 for option 7, whereas the greenhouse gas emissions are similar for both at about 27 kg of CO_2 equivalent per m^2.

Phase 3

Finally, the data were assembled to provide an assessment of the overall embodied energy, greenhouse gas emissions, and financial cost for constructing a typical medium-rise office building with a primary steel frame. Five alternative specifications were assessed for the building. These included the following:

- Typical speculative office building specification
- Lowest cost specification
- Lowest embodied greenhouse gas emission specification

TABLE 1
Environmental and Cost Data Per m^2 for 20 External Wall Specifications

	Wall specification (The wall specification was made up of a series of layers)				**Total embodied energy**	**Total embodied greenhouse emissions**	**Total cost**
	Layer 1	Layer 2	Layer 3	Layer 4	MJ/m^2 of wall	kg CO_2 erquiv/m^2 of wall	£/m^2 of wall
1	Primary facing brick	Expanded polystyrene (EPS), 100 mm	Primary aggregate blockwork	Primary plasterboard	909.9	73.6	£93.46
2	Primary facing brick	Expanded polystyrene (EPS)	Recycled aggregate blockwork	Primary plasterboard	971.4	73.5	£99.09
3	Primary facing brick	Glass wool from recycled glass	Recycled aggregate blockwork	Primary plasterboard	931.3	72.7	£96.08
4	Brick with recycled material	Glass wool from recycled glass	Recycled aggregate blockwork	Primary plasterboard	804.9	58.9	£102.40
5	Reused local brick	Glass wool from recycled glass	Recycled aggregate blockwork	Primary plasterboard	376.6	26.5	£115.06
7	Reused local stone	Glass wool from recycled glass	Recycled aggregate blockwork	Primary plasterboard	388.4	27.4	£161.59
8	Primary facing brick	Mineral wool	Timber frame	Primary plasterboard	738.9	72.9	£93.35
9	Primary facing brick	Glass wool from recycled glass, 100 mm	Timber frame	Primary plasterboard	755.7	71.3	£93.57
10	Primary facing brick	Cellulose insulation	Timber frame	Primary plasterboard	720.4	71.7	£93.47
11	Primary facing brick	Cellulose insulation	Light steel framing	Primary plasterboard	788.6	63.2	£113.43
12	Brick with recycled material	Cellulose insulation from recycled paper, 100 mm	Light steel framing	Primary plasterboard	662.3	49.5	£119.75
14	Steel cladding	Expanded polystyrene (EPS), 100 mm	Light steel framing	Primary plasterboard	426.2	21.8	£117.38
15	Primary aluminium cladding	Expanded polystyrene (EPS), 100 mm	Light steel framing	Primary plasterboard	1,592.3	85.7	£115.59
16	Recycled aluminium cladding	Foam glass with recycled glass, 80 mm	Light steel framing	Primary plasterboard	891.7	51.2	£139.14
17	Steel cladding	Glass wool from recycled glass, 100 mm	Light steel framing	Primary plasterboard	376.0	20.8	£114.62
18	Recycled aluminium cladding	Mineral wool, 100 mm	Primary aggregate blockwork	Primary plasterboard	581.4	40.1	£89.78
19	Reused local brick	Cellulose insulation	Timber frame	Primary plasterboard	186.3	28.5	£112.45
20	Reused local brick	Cellulose insulation	Light steel framing	Primary plasterboard	233.9	17.0	£132.41

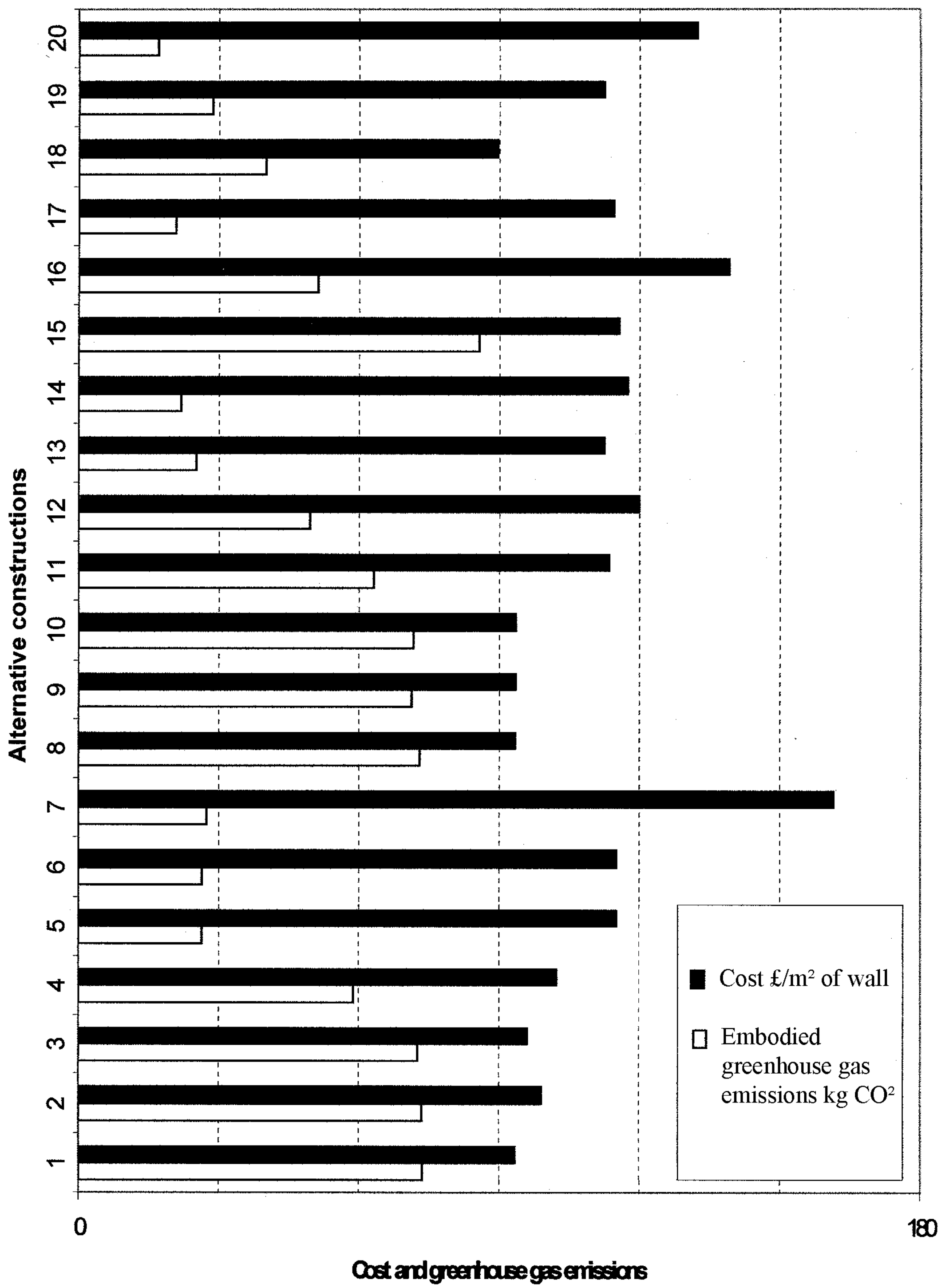

Figure 2 *Greenhouse gas emissions and costs for m^2 alternative wall specifications defined in Table 1.*

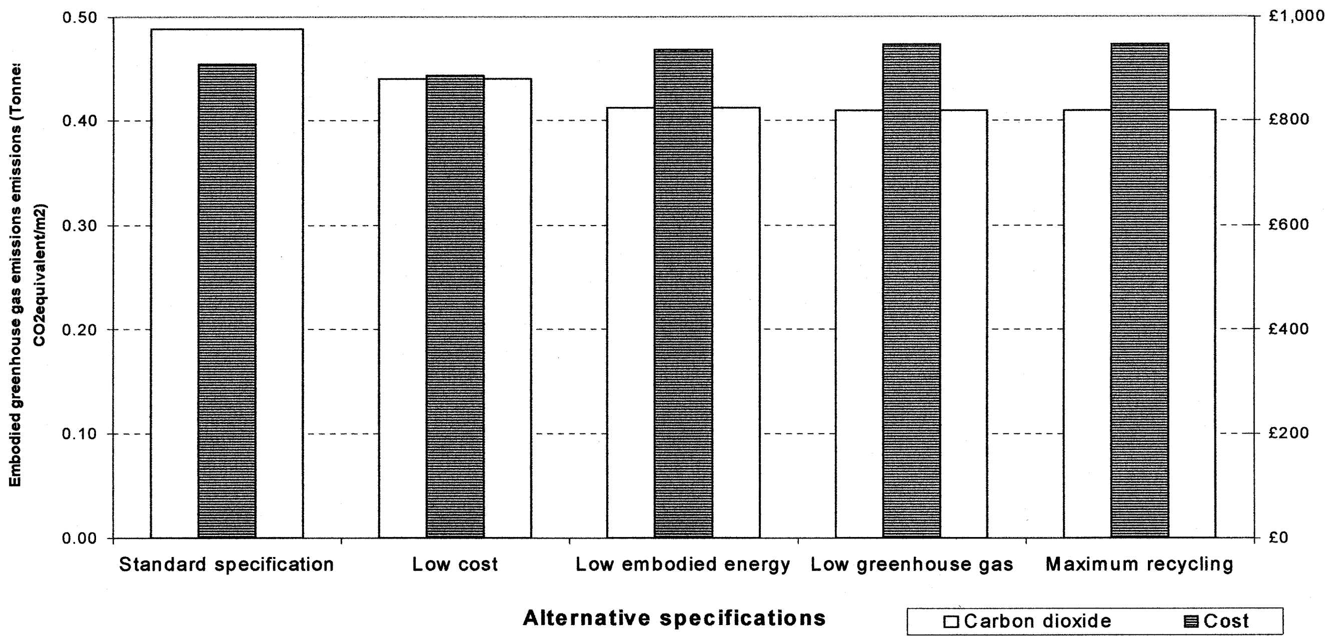

Figure 3 *Comparison of the greenhouse gas emissions and costs for alternative whole building specifications.*

- Lowest embodied energy gas emission specification
- Specification that maximizes the use of recycled materials

The specifications of the walls, roof, and substructure were varied from conventional (primary) materials to recycled and reused materials. Figure 3 shows the total cost and environmental impact for the five alternative specifications considered. This illustrates that there is an additional cost of about 4.5% when choosing the environmentally friendly specifications, but that a 15% saving can be achieved in embodied greenhouse gas emissions by careful material selection (note that only walls, roof, and substructure were varied).

A similar assessment was carried out for roofs and for foundations.

ECONOMIC ISSUES

Based on the experience of collecting cost data during this project and on information from other sources, it became apparent that the cost of using recycled and, in particular, reused products and materials can often attract a price premium. Furthermore, the prices of such products are highly variable, reflecting the state of the local market and on a number of project-specific factors. It is important to point out, however, that this is the current situation and this can be expected to change as the market grows (invoking economies of scale) and as primary material prices rise (enhanced by taxation such as the landfill and primary aggregates taxes).

Project-specific factors to take into account when pricing recycled materials include:

- Distance of the site from a guaranteed supply of the materials (and, hence, transport costs)
- The need for advance purchase (and perhaps storage) of materials to guarantee a supply
- Regional variations in market conditions
- The costs involved in testing

It may also be appropriate to consider the commercial and marketing benefits to the client when developing a project that features recycled materials. Surveys have shown that some clients are prepared to pay a premium for reclaimed and recycled materials (up to 10% has been quoted).

CONCLUSIONS AND DESIGN GUIDANCE

The following guidance has been developed based on the quantitative assessments carried out during this study. It is important to bear in mind that it was not possible to assess resource depletion and waste generation when interpreting this guidance.

- The largest environmental benefits are achieved when using reused components. Specifying these leads to significant reductions in greenhouse gas emissions and embodied energy. However, due to the inconsistency in the supply chain, there is a premium to be paid for the use of reused materials. This is due to the variable supply at present and suggests that the larger environmental benefits gained by using reused components may have some cost penalty.
- The environmental impacts (embodied energy and greenhouse gas emissions) of the external walls are

dominated by the external cladding material. There are several reused options, such as second-hand bricks, or recycling options, such as steel cladding, or bricks with recycled content that can significantly reduce the environmental impact of external walls. It is worth the designer focusing on the specification for the wall cladding.

- The environmental impact (embodied energy and greenhouse gas emissions) of the roof is dominated by the roof structure and cladding. Recycled options, such as steel cladding or tiles made from slate dust, or reused options, such as used concrete or clay tiles, can generate significant environmental benefits. Using steel as the roof structure can also reduce the overall environmental impact of the roof.
- The availability of reused components, such as second-hand bricks and roof tiles, is limited and it may be difficult to secure sufficient quantities from one source. Approaching demolition contractors directly may be the best option. Otherwise salvage yards will need as much notice as possible to source larger batches.
- The correlation between cost and environmental impact is complex. Although the most environmentally beneficial options, particularly reused components, are more expensive, by careful choice it is possible to make cost-effective choices that can significantly reduce environmental impact. Many of the materials that feature some recycled material, such as glass wool or cellulose insulation, are competitive in terms of their costs.
- The correlation between embodied energy, greenhouse gas emissions, and the recycled content is complex. Many materials, such as cellulose insulation, with a high recycled content have a low environmental impact, but this is not the case for all products. Where materials have a partly recycled content, such as steel, the environmental burdens are generally reduced as recycled content increases.
- For most materials, there is a strong correlation between the environmental indicators, greenhouse gas emissions, and embodied energy. However, there are some variations and, in particular, the situation for timber is complex. For timber, the carbon sequestered during growth is offset by the carbon dioxide and methane generated when it is disposed. The overall result is that although embodied energy is relatively low, greenhouse gas emissions are more significant.
- Standardization of components would greatly enhance the match between those retrieved from old buildings and those required for new buildings. Many architects would like to reuse old elements but find it difficult to locate suitable supplies. Equally, many demolition contractors would like to sell whole building elements for reuse, but the timing of the demolition contract rarely coincides with demand for those elements. Supply and demand of recycled construction products is currently too erratic for a stable market in reused elements to exist. However, this barrier is not insurmountable, and with a certain amount of "pump-priming" from the construction industry and the imposition of "green" taxes on primary construction materials, supply and demand should be better matched in the future.
- The elements assessed in this study (external wall, roof, and substructure) form only about 20% to 25% of the environmental impact of the whole building. The study has shown that it is possible to reduce the environmental impact of these elements by up to about 50% by careful specification, particularly of reused components. There are fewer options for using recycled materials for other elements, and it is unlikely that savings on this scale could be made.

The project also led to the conclusion that there are few environmental data that are sufficiently comprehensive to calculate environmental indicators such as resource use and waste generation, in particular, for materials that are recycled or reused. Where comprehensive data are available, there is often reluctance by the manufacturers or trade associations to release this information. Furthermore, it is clear that there is no agreement about methodologies that are appropriate for calculating the environmental benefit of recycling or reuse of materials, such as steel, when carrying out a life-cycle assessment.

ACKNOWLEDGMENTS

The study reported in this paper was conducted by the Steel Construction Institute, Corus, Davis Langdon & Everest, and the Building Research Establishment in the U.K.

REFERENCES

BRE. 1999. Environmental profiles database available on the internet at www.bre.co.uk. Building Research Establishment.

IISI. 1999. *Life cycle inventory for steel*. International Iron and Steel Institute.

Ecobillan. 1999. TEAM database.

SCI. 2000. Concept study and economic assessment of a recycled building using a primary steel frame. Steel Construction Institute.