Study of current building methods that enable the dismantling of building structures and their classifications according to their ability to be reused, recycled or downcycled.

Paola Sassi Dipl Ing MSc RIBA

School of the Built Environment, University of Nottingham, University Park, Nottingham NG7 2RD United Kingdom Phone +44 (0)115 954131 Email paola.sassi@nottingham.ac.uk

INTRODUCTION

Waste minimisation is increasingly being adopted in the UK as one of the means to reduce the environmental impact of buildings. Waste minimisation relating to construction can involve activities during the whole building life cycle ranging from streamlining construction processes to reclaiming building components for reuse at the end of the building's life. The UK government formulated a waste hierarchy shared by academics as part of the *Waste Strategy 2000 for England and Wales* [i]. This hierarchy puts waste avoidance as the top priority to minimise waste, followed by reuse of waste, then recycling, downcycling, incineration to produce energy and finally landfilling. The hierarchy is based on the environmental benefits associated with the different waste minimisation strategies, which are:

- waste avoidance reduces the amount of waste produced:
- reusing, recycling and downcycling waste puts waste to new uses thereby helping to conserve energy [ii] and resources, reduce pollution, minimise the impact of resourcing on natural habitats and reducing waste going to landfill and the associated land use and pollution;
- incineration diverts waste from landfill and recovers some of the material's embodied energy.

At the end of a building's life, it can either be demolished or it can be dismantled and the elements and materials reused and recycled. The most environmentally beneficial use of waste is to reuse it, reuse being associated with higher reductions of embodied energy and emissions to air and water compared to recycling. [iii] However recent surveys undertaken by the Department of Environment, Transport and the Regions estimates a minimum of 53 million tonnes of construction and demolition waste being produced annually in the UK, of which 24 million tonnes of inert waste are recycled (recycled and downcycled) and only 3 million tonnes is reclaimed for reuse. [iv]

The low reuse and relatively low recycling rates reflect a number of barriers to recycling and reuse including the fact that most building elements are not currently designed for dismantling and the resulting excessive time requirements for dismantling coupled with low disposal costs make dismantling a prohibitively expensive process[v]. Demolition contractors report that deconstruction can take two to ten times longer than demolition efforts putting deconstruction at a distinct economic disadvantage.[vi] However economics is not the only barrier to reuse and recycling. Current building codes and certification systems do not generally deal with reclaimed materials and elements and where the element's performance is not a crucial issue, aesthetics and commercial desirability may be instead. Consequently even if a building material or element is capable of being dismantled from a technical and economic point of view, it still may not be reused or even recycled due to the lack of a market for uncertified products or those of lesser aesthetic appeal.

Despite the fact that most current building methods are intended for permanent installation, some building materials and elements are being reclaimed. Contractors report that reclaiming asphalt, concrete, timber, metals and historic salvaging, for recycling or reuse can represent 20 to 40% of some demolition companies' revenues[vii]. There are also some building systems that have been designed for flexibility (such as demountable office partitions), ease of installations (toilet cubicles) and even reuse (temporary buildings) and these systems are easily dismantled facilitating their reuse and recycling. Some building product manufacturers have even gone a step further and are addressing the issues of waste associated with their products by reviewing their whole business principles and integrating recycling as part of their products' life cycle. Both Interface and Milliken Carpets now offer a service to take back used carpet and recycle and recondition the carpet respectively giving them a second life. The current building industry does offer designers the products to produce buildings that can be dismantled and their building elements reused or recycled, however what is required is an assessment of which systems and products do provide these facilities and how effective they are in this respect.

The aim of this study was to develop a system to assess building products and materials for their reuse and recycling potential, which could be used to classify products and materials and facilitate the design of recyclable and reusable building systems.

DEFINITIONS

For the purpose of this study the following definitions were used:
reuse refers to when elements are minimally reprocessed and reinstalled in a building without having to be remanufactured
recycling involves complete remanufacturing to produce the same type of building element
downcycling involves complete reprocessing to produce a different and lower grade building element.

METHODOLOGY

The study selected sixty building methods and products typically used in construction in the UK and analysed their composition, installation system and durability in relation to their intended use and to the dismantling process. The building methods and products were grouped by building element type including: structural systems, external wall constructions, roof finishes, internal partitions, secondary elements, ceiling, floors and wall finishes. The building methods and products were then evaluated in terms of their suitability for reuse, recycling or downcycling using a set of criteria derived from previous research into guidelines for designing for dismantling and recycling.

The guidelines and principles for designing buildings for dismantling, reuse and recycling developed in the last five years [viii ix x xi] focus on two main areas: 1/ the process of removal of building elements and materials from building structure and 2/ the requirements for reprocessing of building elements and materials to enable reintegration in a new building.

To facilitate the removal of elements and materials from a building, these have to be designed to be technically capable to be removed with as little effort and as quickly as possible. A quick and effortless dismantling process will reduce costs of dismantling, which will then begin to compete with the cost of a standard demolition process and become more economically attractive. Effective dismantling is desirable whether the building elements are to be reused, recycled or down cycled. To achieve building designs that can be efficiently dismantled the following points should be considered.

- INFORMATION - Provide As Built drawings and Maintenance Log including identification of points of disassembly, component and material and identify materials and points of disassembly on elements.
- ACCESS - Provide easy and safe access to building element and fixings with minimal machinery requirements.
- DISMANTLING PROCESS - Simplify fixing systems and enable removal by means of small hand tools and handheld electrical tools avoiding specialist plant. Use mechanical rather than chemical fixing. Provide realistic tolerances for assembly and disassembly. Design joints and components to withstand dismantling process.
- HAZARDS - Make components sized and of a weight to suit the means of handling and provide means of handling and locating. Avoid toxic materials.
- TIME - Minimise number of parts, fixings and types of fixings and allow for parallel disassembly.

Once removed from the building, elements have to be reprocessed to enable their reuse or recycling. The nature and amount of preparation work required will depend on the characteristics of the elements and the designated use. Taking into account that reusing elements provides the greatest environmental benefits, the following recommendations aim to maximise the ability for the materials and elements to be reused, but also aim to ensure that once the element can no longer be reused it is capable of being recycled.

- REPROCESSING - Use materials that require minimal reworking, avoid non-recyclable materials such as composite materials and treatments and secondary finishes to materials that complicate reprocessing. Minimise the number of different types of components and ensure inseparable subassemblies are from the same material and components of different materials are easy to separate. Flexible installation options included.
- HAZARDS - Minimise toxic content, if toxic content is unavoidable ensure the ability to release it in a controlled manner. Make components sized and of a weight to suit the means of handling and provide means of handling and locating.
- DURABILITY - Use sturdy and avoid fragile material. Design joints and components to withstand repeated use.
- INFORMATION - Provide identification of material and component types. Provide product details and installation instructions.

The criteria derived from the above guidelines are listed in Table 1 and were used to assess materials and elements and calculate an index value to enable comparisons. The criteria are grouped to enable each element to be independently assessed for its suitability for reuse, reuse as new, recycling and downcycling. The criteria are also divided into those that assess the technical ability of materials to be reclaimed and those that assess issues affecting the cost of reclaiming materials. The criteria that assess the technical ability were given a higher weighting than those affecting the cost as the total cost will be dependant on issues other than design including location of project, labour costs etc, while the technical ability to dismantle elements is essentially dependent on the design of the building system, which may require a complete redesign if dismantling is desired.

The criteria differentiate between reuse *as new* and reuse *as second-hand product*. This addresses the issue of marketability of used building components. There is a distinct prejudice against second-hand products without historic appeal. While a Victorian fireplace will attract a respectable resale price, second-hand modern sanitary ware is very difficult to resell at all. To achieve the *as new* qualification does not necessarily involve actually appearing brand

new, achieving a suitable aged or rustic appeal will prove equally acceptable to the buying public. Where a material only achieves a standard for reuse as a second-hand product it is to be expected that its range of possible applications may be limited for certain products.

Criteria	Top rating	Bottom rating
Criteria for suitability for general dismantling		
Installation system, fixing methods	8 - Fully accessible fixings / simple installation / standard equipment required	2 – Installation precludes dismantling
Access to and handling of building elements	4 - Direct access for single person with simple equipment	1 - Specialist supports and machinery required
Hazards (toxins, structural, handling)	4 – None	1 - Special precautions/ equipment necessary
Time required to dismantle elements	4 - Low - can run in parallel to other activities	1 - Very high - dependant on other activities taking place to enable dismantling
Information required to dismantle element	4 - None required, standard installation	1 - Hazardous to dismantle without guidance
Criteria for suitability for re-use as second-hand item		
Reprocessing requirements to enable reuse	8 - Minimal, check for faults and clean	2 - Impossible to reuse
Durability	8 - Durable non-fragile element and fixings	2 - Dismantling is likely to result in damage of element
Components and sub-components	8 - Single element / no separation required	2 - Specialist machinery required to separate
Hazards	4 – None	1 - High risk / special precautions required
Requirements for performance compliance	4 - Visual test sufficient	1 - Major test regime required
Information required for reinstallation	4 - None required, standard installation	1 - Information essential to avoid hazardous installation
Fixings required for reinstallation	4 - Non-specialist interchangeable fixings	1 - Specialist non-replicable fixings
ADDITIONAL criteria for suitability for reuse as new		
Requirements to ensure aesthetic standards	4 - Aesthetics non-critical / easily achieved	1 - 'As new' aesthetic unachievable
Criteria for suitability for downcycling and recycling – assessed separately		
Reprocessing requirements	8 - Minimal preparation before reprocessing	2 - Impossible to recycle or downcycle
Durability	4 - Non-critical to recycling process / very durable	1 - Prone to disintegrate and preclude recycling
Hazards	4 - None additional	1 – Specialist protection required

Table 1 Criteria for establishing suitability for reuse / recycling / downcycling
Rating range from 4 (most suitable) to 1 (least suitable) for cost linked criteria and from 8 to 2 for technically linked criteria with a higher weighting

RESULTS

The study highlighted a number of problem areas, but also showed that there is potential for designing reusable and recyclable structures. The following aspects to consider emerged.

Interlinking elements - Building elements are interlinked as one layer of the building structure is supported on another. If the installation method of one element precludes its own reuse and recycling it is likely to also preclude the reuse or recycling of the linked elements. Wall and ceiling finishes are prime examples of this affecting the reusability and recyclability of their substrates. While mechanically fixed boarding materials (e.g. timber, plastic) can easily be removed allowing the fixings of the support structure to be accessed and ultimately enabling its dismantling, applied finishes (e.g. plaster, tiling) can make the access to the support structure fixings difficult and in some cases impossible and can also contaminate the substrate material precluding its recycling (e.g. plaster on blockwork).

Composite materials – The composite elements studied often proved easy to reuse, but impossible to recycle, confirming the guidelines produced for designing for recycling that recommend avoiding composite materials.

Materials – Different materials proved particularly suited to specific reprocessing techniques: metals being easily recycled, concrete most easily downcycled and timber easily reused.

Prefabricated elements - Prefabricated elements often rated highly in terms of their reuse potential, but some rated quite low in terms of their recycling potential as the ability to be recycled is dependant on the design of the unit itself, which often included composite material that could not be recycled or downcycled.

Certification – Reuse of such products as roof membranes, structural elements or insulation material can be hindered by the lack of certification of the elements' performance. Provision of information on the building products may partially eradicate the problem, but in certain cases testing will still be necessary adding to the cost of reusing the products. Recycling building elements circumvents the issue of product certification.

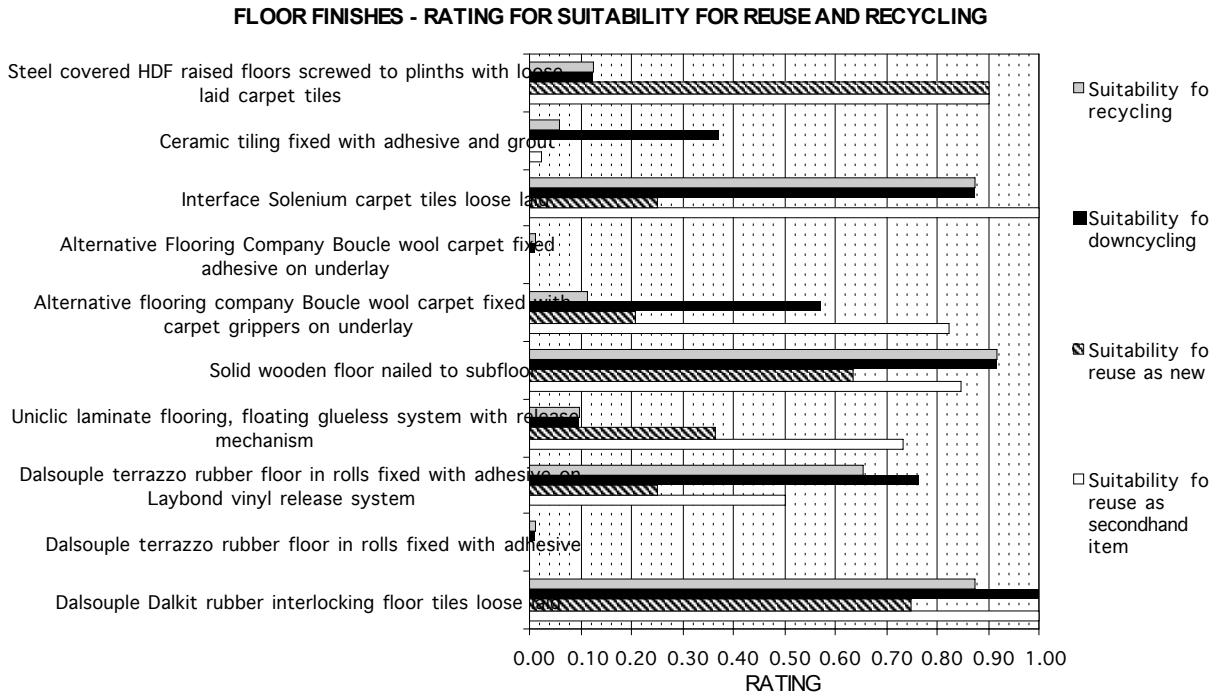

Table 2 - Graph showing rating for suitability for reuse / recycling for selected floor finishes

Aesthetics – Aesthetic barriers can hinder the reuse of building elements. This clearly applies to visible elements and perhaps applies more to internal building elements than to external building elements. The ability to reapply a finish to a product to be reused could prove invaluable in terms of reusing such items as toilet cubicles that are dismantled with extreme ease, but are normally not reused due to their second-hand appearance in a building area where a second-hand look is not considered acceptable. In particular where elements are of standard sizes, such as doors the ability to reapply a finish would make what is an easily reclaimed standard sized item very marketable. Being able to reapply a finish would also address the issue of design fashion, enabling building elements to be upgraded to the current fashion requirements.

Unit size – The reused potential of building products and elements is affected by the design flexibility afforded by the reclaimed item. Building elements made of small units such as bricks in brick walls or rubber tiles for floor finishes, allow for the units to rearranged to suit different designs. At the opposite end of the spectrum are building elements such as windows or prefabricated wall panels made of different types of units acting together as one, which if reused will dictate what the design will be. This limited flexibility constitutes a substantial barrier to their reuse.

CONCLUSION

Some areas of building design represent a particular challenge in terms of achieving easily reusable and recyclable buildings, while others already provide a good choice of recyclable products. However there is still a need to refine current designs to accelerate the dismantling process where it is already possible and enable it where it is currently impossible.

On the technical side, building finishes pose possibly the most serious technical and aesthetic problem, as the existing options that enable dismantling are not those traditionally used that appeal to the general public and the aesthetically acceptable options are often not dismantleable. As illustrated in Table 3 a commercial building designed for recycling and reuse may be in part visually indistinguishable from a traditional building designed for permanence, but a domestic building designed for recycling and would appear very unusual.

Domestic building	**Commercial building**
Concrete foundations and slab (recyclable)	Concrete frame (recyclable)
Timber frame (reusable / recyclable)	Mechanically fixed curtain walling & rainscreen stone cladding (reus./recyclable)
External walls brick cladding (reusable / recyclable)	Mechanically fixed EPDM roofing membrane / insulation (reusable./ recyclable)
Tiled roof (reusable / recyclable)	Relocatable steel and glass partitions (reusable/ recyclable)
Internal timber wall & ceiling panelling (reusable/recyclable)	Suspended metal ceiling (reusable/ recyclable)
Loose laid rubber /timber flooring (reusable / recyclable)	Raised floors (reusable) with Interface carpet tiles (recyclable)
Mermaid panels to wet areas (reusable)	Toilets cubicles (reusable) – loose laid rubber flooring (reusable/ recyclable)

Table 3 – Outline specification for reusable / recyclable building design

On a psychological level, a change of mindset is required not only in terms of aesthetics, but also in terms of adopting and promoting reuse and recycling as a truly economically viable and desirable option, not only by clients, but by all the construction industry.

Finally it is often the case that building products can be installed in a number of different ways that differently affect the product's recyclability. It is therefore through careful specification as well as considered building products selection that a dismantleable and reusable or recyclable building solution can be produced. Perhaps a model specification such as those already in use in the UK (National Building Specification), but one with the purpose of defining and specifying dismantleable, reusable and recyclable buildings would provide the most effective support for designers wanting to ensure maximum reuse and recycling.

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