Biodegradable building

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Abstract

Waste minimisation is increasingly being considered as part of a comprehensive approach to sustainable design. Good site practice and procurement systems can realise some reductions in construction and demolition waste, but to significantly reduce waste and create a virtually zero waste building changes in the building design are necessary. To achieve zero waste buildings, inspiration can be drawn and lessons can be learnt from nature. The cyclical characteristic of natural processes, where plants grow, die and biodegrade becoming a resource for new growth, can be applied to building construction. The concept of biodegradable buildings relates to nature at a theoretical level and its implementation in practice can contribute to a comprehensive agenda for sustainable design.

This paper reports on a study of the potential for reducing end of life waste associated with buildings by constructing buildings to be biodegradable, and considers the options for integrating biodegradable materials in mainstream construction. The study compares the end of life waste produced by three building designs including a traditional construction, a mainstream advanced design and a maximum biodegradable design. The results identify possible waste reductions of 85% of non-biodegradable waste measured by weight and 93% measured by volume for the advanced design and 99.6% (weight) and 99.9% (volume) for the maximum biodegradable design compared with the traditional construction. Both designs also achieved overall waste reductions of approximately 70% by weight and 20% by volume. The study concludes that feasible and worthwhile waste reductions can be achieved in mainstream housing construction by designing biodegradable buildings.
Keywords: waste minimisation, biodegradable materials, recycling, natural materials ecological building.

1 Introduction

Designing sustainable buildings involves addressing a broad spectrum of issues. A comprehensive approach to sustainable building design addresses large scale and urban design issues affecting community stability, social well-being and the environment, as well as building-related issues affecting resource use and human and environmental health. Certain sustainable design approaches, such as energy efficiency, are well understood and extensively implemented; others are still at an experimental stage and seldom put in practice. Among the less widely implemented sustainable design approaches is that of minimising construction and demolition (C&D) waste. However, with increasing environmental concerns also this area is now being addressed.

Waste from construction and demolition work constitutes a significant percentage of the total 400 million tonnes of waste produced in England and Wales, which include industry, commerce, household, agricultural and mining wastes, plus sewage sludge and dredged spoils [1]. An estimated 90-120milion tonnes of C&D waste per annum are produced in the UK, of which 15-20 million tonnes are thought to be construction waste, the rest is demolition waste [2]. Most of the demolition waste measured by weight is concrete (making up 40%) and masonry (24%). The remaining demolition waste is made up of paper, cardboard, plastic (17%), asphalt (15%), wood based (3%) and other materials (0.6%). Approximately half of the inert waste is used as fill materials in landscaping and road building, as little as 3 million tonnes of the total C&D waste is reclaimed for reuse in the building industry and most of the rest currently goes to landfill [3]. An estimated 16 million tonnes of C&D waste designated for landfill is classified as special waste requiring treatment before being landfilled. Biodegradable waste makes up less than 20% of the total demolition waste and some of it, such as treated timber, is sometimes classified as special waste [4].

Waste is associated with a number of environmental problems. The transport of waste is associated with pollution to air and resource consumption. Waste disposal through landfill is associated with the use of land, which in many densely populated countries is becoming a scarce resource [5], and with pollution to land, water and air [6]. Incineration also generates pollution and contaminated ash, which is generally landfilled.

To reduce the environmental impacts associated with waste both the amount and the pollution potential associated with the waste should be minimised. The Waste hierarchy determined by the EC Framework Directive on Waste (Council Directive 75/442/EEC) sets out waste options in descending order of environmental benefit. Prevention or minimisation of waste is identified as the most preferred waste minimisation solution. This is followed by reuse; recovery, which includes recycling and composting; energy recovery from waste through incineration; and finally disposal through landfill [7].

In respect of building design, prevention or minimisation of waste begins at design stage and can be addressed by making efficient use of building materials through value engineering, but also by only building what is really necessary. In terms of material selection to minimise waste, inspiration can be drawn and lessons can be learnt from nature. The cyclical characteristic of natural processes, where plants grow, die and biodegrade becoming a resource for new growth, can be applied to building construction. Such a cyclical, or closed loop, system for buildings and their materials could be created through the use of both biodegradable and recyclable materials. In both cases the existence of a closed loop systems is subject to the segregation of waste when it occurs i.e. during the demolition or dismantling of the building, as well as during maintenance work. Biodegradable materials are part of a naturally occurring closed loop cycle. Recyclable materials are part of a closed loop 'man-made' cycle. While the waste hierarchy puts reuse above recycling and composting in respect of reducing the environmental impacts associated with waste, only if a reusable element or material is also biodegradable or recyclable can it form part of closed loop cycle. The reuse of components or materials that are not recyclable or biodegradable may extend their useful life, but they will nonetheless constitute part of a linear system, typically associated with high levels of waste, rather than a cyclical system. To maximise the waste minimisation efforts materials should be both reusable and part of a closed loop cycle [8].

From an environmental point of view closed loop cycles of biodegradable materials are preferable to those of recyclable materials as they generally require fewer reprocessing resources and are associated with less pollution. For example: the embodied energy of imported timber is 3 MJ/kg, a third of that of recycled aluminium estimated at 9.2 MJ/kg (5% of 184 MJ/kg for virgin aluminium) [9]. The 'reprocessing' of timber through natural cycles involves the timber biodegrading. This can produce carbon dioxide through aerobic decomposition or methane through anaerobic decomposition. The resulting compost can replace peat and artificial fertilisers and methane can be used as a fuel. Trees absorb carbond dioxide through their growing period and also provide other benefits such as natural habitats for flora and fauna, soil erosion prevention, environmental cooling and much more. The reprocessing of aluminium, on the other hand, is an industrial process associated with pollution to air albeit reduced compared to the production of new aluminium.

2 Research aims

Reducing waste associated with buildings throughout their lifetime by designing closed loop material system composed of biodegradable materials is not part of mainstream practice. As could be seen from the composition of demolition waste, only a small percentage is biodegradable. Timber, an extensively used biodegradable material, only makes up 3.1% of the total materials used. To increase the use of biodegradable materials in buildings, a broader range of products is required. Furthermore a clear case has to be made for the use of biodegradable materials as an effective approach to waste minimisation.

This study considered the potential for constructing buildings, and in particular mainstream housing, with biodegradable materials as a means of reducing end of life waste associated with buildings demolition and deconstruction. Currently available biodegradable building materials were identified, including those in common and less common use, and assessed for their appropriateness for use in mainstream housing construction, by comparing their cost, technical performance and aesthetic equivalence to that of standard materials. To quantify the potential for reducing waste through the use of biodegradable materials the construction specification of three different house types was compared to assess the volume of biodegradable and non-biodegradable waste that would be produced at the end of the buildings' life. The designs discussed in section 4 ranged from conventional to highly biodegradable.

3 Biodegradable building materials

Biodegradable - Property of a substance that enables it to be decomposed by microorganisms. The end result of decay is stable, simple compounds (such as water and carbon dioxide). This property has been designed into materials such as plastics to aid refuse disposal and reduce pollution [10].

While biodegradability is often associated with natural materials, as the above definition suggests, man-made materials can also be made to biodegrade. Natural biodegradable building materials have a very long history, but with the advent of synthetic and contemporary materials, biodegradable materials have progressively lost their share of the building industry market. However, increasing environmental concerns have again brought natural materials to the fore as well as pushed the plastics industry to develop biodegradable plastics.

Biodegradable materials can be grouped in four categories: natural materials that can be used following minimal processing (e.g. timber, bamboo); natural materials bonded with a resin or mesh (e.g. sisal carpet, soy boards); natural compounds used in manufacturing products including adhesives and other polymers (e.g. natural protein to manufacture biodegradable plastics); and biodegradable synthetic materials (biodegradable plastics).

3.1 Minimal processing natural biodegradable materials

In contemporary construction, natural biodegradable materials that need minimal processing include timber, straw and bamboo used for structural purposes; straw, cork, flax, hemp and sheep's wool insulation; cork floor and wall finishing; bamboo and timber rigid floor finishes; timber and thatch timber roofing finishes; and timber fixtures and fittings, including bathtubs and sinks.

3.2 Bonded biodegradable materials

Examples of bonded biodegradable materials include mixtures of hemp or straw and clay used to infill external wall frames; straw bonded between two layers of kraft paper to form non-loadbearing internal partitions; timber, straw and soy finishing or structural boards; jute carpet backing and wall coverings; seagrass, sisal, coir, cotton, paper and wool carpeting; cork mixed with wood flour, powdered limestone, linseed oil and natural resin to make linoleum. Natural fibres have been shown to have equivalent performance characteristic to synthetic fibres, [11] and their use in concrete and cement products has generated great interest in the research community [12]. However, bonding a biodegradable material with a non-biodegradable material, such as concrete or cement will compromise overall biodegradability. Similarly effects may occur when including additives to improve the performance of building products. For example some insulation products made with natural and polyester fibre mixed are unsuitable for composting, but equally inappropriate for landfilling due to the large percentage of organic matter [13]. Some bonding mediums, such as the kraft paper in straw walls or the natural resins in hardboards are themselves biodegradable, others are not. To maximising the biodegradability of building products natural fibres should be bonded with the biodegradable naturally derived high performance plastic resins, as discussed in the next paragraph.

3.3 Natural biodegradable plastics

Biodegradable plastics, which include adhesives and resins, can be made from naturally occurring polymers such as cellulose, starch, protein, and sugar molasses extracted from plants. Historically natural adhesives, such as potato and rye flour starch, soya protein and natural rubber have been used very successfully, and while still in use are now largely superseded by higher performance synthetic glues [14]. Research is now focussing on manufacturing natural and biodegradable plastics with performance characteristics equivalent to synthetic options. Corn zein, wheat gluten, soy protein, and peanut protein have been investigated for potential uses. New building products made in this way are not yet available, but industries such as the paper and colouring industry are beginning to replace synthetic polymers with natural ones [15]. The packaging industry is also making use of natural plastics for food packaging and protective mouldings. The use of expanded starch packaging is already relatively widespread and could be introduced to building industry [16].

3.4 Synthetic biodegradable plastics

Petroleum-based plastics, mainly polyolefins such as LDPE in, LLDPE, can now be modified with additives to be made biodegradable and able to be converted through digestive activity of microorganisms into water and carbon dioxide [17]. Current uses include biodegradable waste bags. Building products made with synthetic biodegradable plastics are unlikely to be developed for the time being, due to the higher manufacturing costs, but could be developed in future.

3.5 Technical aspects of ensuring biodegradability

To ensure that material integrated into a building can be biodegraded at the end of the building's useful life, the building elements' installations in the building as well as their material characteristics have to be considered.

3.5.1 Building element installation and deconstruction

As with any form of closed loop material cycle, being able to recover different materials separately is essential to enable their composting or recycling. Demolition is therefore an unsatisfactory end of life disposal approach as it results in a mixture of different waste types, which are time-consuming and costly, if not impossible, to separate. Deconstruction, on the other hand, enables the segregation of waste types. For building that are 100% biodegradable separating waste would not be necessary, but as becomes evident later, in mainstream construction 100% biodegradability is unrealistic at the moment.

To facilitate the deconstruction, building elements should be mechanically fixed, preferably with few fixings; easily accessible; easily handled with minimal associated health hazards; and able to be deconstructed using simple tools and with minimal additional information [18, 19].

3.5.2 Building element components

To be suitable for composting, a material recovered from the dismantling of a building must also be as pure as possible. As discussed in section 3.2 a careful analysis of the constituent parts of a predominantly biodegradable material is necessary to establish whether it is in fact biodegradable. Treatments, as well as additives, can hamper the biodegrading process by slowing down the process and creating a non-biodegradable residue, which, as with some timber treatments, may also be toxic. Treatment may, however, be essential in improving the product durability and further development of safe treatments could contribute to creating more biodegradable buildings.

To maximise biodegradability in practice materials may also need to be identified as being biodegradable. Awareness of the biodegradability of materials such as timber is widespread, but knowledge of new plant-based boards and biodegradable plastics is limited. Furthermore some biodegradable materials cannot be visually distinguished from their non-biodegradable counterparts. In this respect, a tagging system, as used in the plastics recycling industry, and a comprehensive account of the materials installed may prove essential.

4 The use of biodegradable materials in practice

Mainstream construction makes little use of biodegradable materials. The main mainstream biodegradable material used is timber and even this material may be rendered non-biodegradable by the way it is installed. The increase in use of synthetic adhesives to fix skirting or bond floor finishes to a substrate can made the building element and the substrate non-biodegradable. Yet, there is currently a good selection of materials that are biodegradable and can be installed in a way to retain this characteristic.

To assess the waste reduction potential of biodegradable buildings, this study compared the amount of biodegradable and non-biodegradable waste that would be produced at the end of the life of three different specifications for a typical three bedroom detached two storey house. The three house plans and their thermal performance are identical. The structure, in view of the government drive for prefabrication, is timber in all three cases, but other elements vary. The material specifications for House 1 and 2 are based on completed projects studied by the author [20]. House 1 comprised materials typically used by UK housing developers and is based on the 21st Century homes in Aylesbury by Briffa Phillips Architects for Hightown Preatorian Housing Association. House 2 is a mainstream advanced design and comprised commercially available biodegradable materials keeping in line with current aesthetic expectations and is based on the Toll House Gardens in the Fairfield estate, Perth, Scotland, by Gaia Architects for Fairfield Housing Co-operative. House 3 maximises the use of biodegradable materials choosing where possible but not limiting the choice to the most commercially realistic materials. All three house structures were detailed and the volume and weight of the materials included in the buildings were measured. Services and fixtures and fittings were not included in the assessment. The materials compared and used in the model specification are identified in Table 2. When assessing the biodegradability of the materials specified the following three issues were considered.

1. Constituent materials of building elements.
2. Finishes and treatments that may compromise biodegradability.
3. Fixing methods that would compromise biodegradability.

The main differences in the house types include:

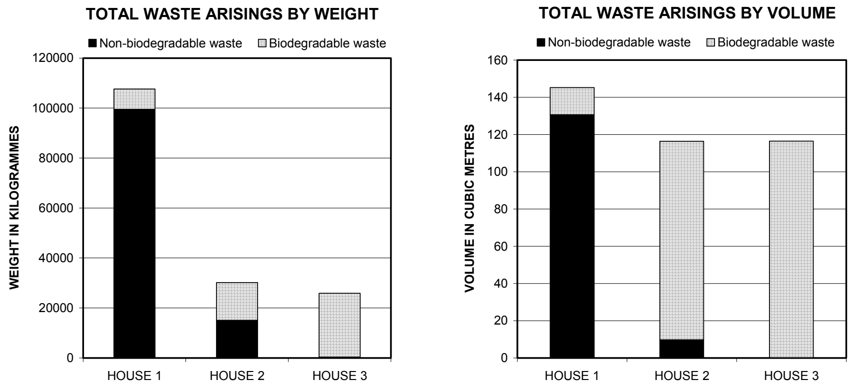
1. House 1 has a concrete ground floor bearing slab, while House 2 and 3 have suspended floors and House 3 includes timber piles.
2. The external cladding material in House 3 is timber, while House also has brick and House 2 render elements.
3. The internal finishes in House 1 and 2 are applied (skim finish to plasterboard), while in House 3 mechanically fixed self-finished products are used.

Table 1.

WASTE ARISINGS	measured by weight (kg)			measured by volume (m³)		
	House 1	House 2	House 3	House 1	House 2	House 3
non-biodegradable	99501	15076	355	131	10	0.2
	92.5%	50.0%	1.4%	90.0%	8.4%	0.1%
biodegradable	8111	15090	25522	15	107	116
	7.5%	50.0%	98.6%	10.0%	91.6%	99.9%
TOTAL WASTE	107612	30166	25877	145	116	117

4.1 Waste reductions achieved

House 1 design resulted in 99.5 tonnes of non-biodegradable waste and 8 tonnes of biodegradable waste. House 2 design resulted in 85% reduction of non-biodegradable waste measured by weight and 93% reduction by volume compared with House 1. The biodegradable waste increased, but the overall waste was reduced by 72% by weight and 20% by volume. House 3 design resulted in 99.6% reduction of non-biodegradable waste by weight and 99.9% reduction by volume compared with House 1. Total waste was reduced by 76% by weight and 20% by volume. Table 1 and Figures 1 and 2 show the amount and percentage of biodegradable and non-biodegradable waste for each option.



Figures 1 and 2: Waste arisings by weight and by volume.

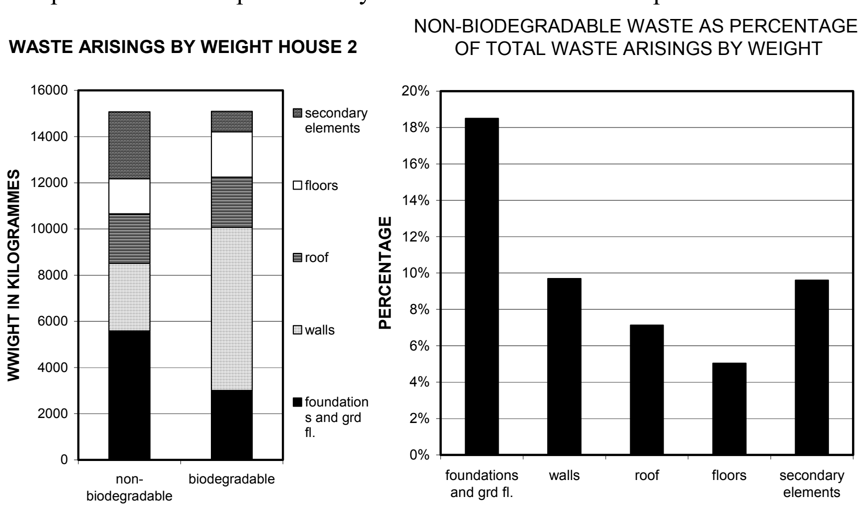
Table 2.

Specification comparison for house types 1, 2 and 3 and assessment of biodegradable option Key: High= ● Medium=◖ Low=○ Used in: House 1= ① House 2=② House 3=③			**Cost equivalence**	**Technical performance**	**Aesthetic conformity**	**Mainstream acceptance**
Building elements	**Non-biodegradable material**	**Biodegradable building material options**				
Foundations	Concrete ①②	timber③	◖	○	◖	○
Frame		timber①②③	●	●	●	●
Insulation below ground	Expanded polystyrene①					
Insulation between studs	Rockwool①	Recycled cellulose fibre (Warmcell) ②③	◖	●	●	●
External insulation	polyurethane①	Wood fibre insulation (Diffutherm) ②	◖	◖	●	●
Wall panel lining	OSB ①	Hardboard (Paneline /Panelvent)②③	◖	●	●	●
Vapour control	PE① / ②					
External cladding	Brick① Render②	Timber①②③	●	●	●	●
Roof finishes	Concrete Tiles① Slates②	Timber③	◖	◖	●	◖
Rainwater goods	PVC① Metal②	Timber ③	○	○	◖	○
Windows doors		Timber①	●	●	●	●
Floor panel lining	Chipboard ①	Timber ②③	◖	●	●	●
Internal wall & ceiling finishes	Plasterboard①②	Ply with natural glues ③	○	●	◖	◖
Floor finishes	Carpet① Vinyl① Ceramic tiles ②	Timber③②	●	●	●	●
		Cork③	◖	◖	●	●

4.2 Barriers and opportunities to maximising biodegradable materials

The main sources of non-biodegradable waste can be identified by analysing the amount of non-biodegradable waste resulting from House 2 option, designed to maximise biodegradable waste with a design suitable for mainstream construction. As shown in Figure 4, non-biodegradable waste from foundations and the ground floor makes up 19% of the total waste. This can be accounted for by the use of concrete in the foundations and represents the biggest barrier to creating mainstream biodegradable houses. House 3 makes use of timber foundations, but this approach, due to the limited durability of timber foundations, is inappropriate for mainstream construction. A potential environmental improvement would be to use prefabricated concrete foundations that can be reused and recycled.

A second significant source of non-biodegradable waste is plasterboard, accounted for in the construction of the walls and roof. House 3 replaces plasterboard with ply bonded with natural glue, other biodegradable finishes would include timber boarding or cork, but none of these at the moment are acceptable by the general public, who expects smooth plastered walls. The performance of all the alternatives is equivalent to that of plasterboard and it is a perception barrier that prevents any deviation from the use of plastered finishes.



Figures 3 and 4: House 2 waste analysis.

In House 1 the potential for biodegrading the timber structure, which is generally very easily dismantled and can be biodegraded, was reduced in comparison to House 2 by the use of adhesive fixings for floor finishes and skirting.

Two small but difficult to overcome sources of non-biodegradable waste identified are glass and metal fixings. In House 3 this represented a very small amount of waste: 1.4% by weight and less that 1% by volume. Both materials are however recyclable. Other similarly difficult products not covered by this study include electrical wiring, second fix electrical goods (e.g. socket outlets, switches), water supply and disposal, which are now generally made of non-biodegradable plastics. Here too metal alternatives exist. It is perhaps to replace these types of products that research into biodegradable plastics would be worthwhile.

5 Disposal of biodegradable materials

To realise the waste minimisation advantages of using biodegradable materials a number of issues have to be addressed. These include technical aspects of building design and materials specification, as discussed in section 3.5; the facilities for and infrastructure associated with waste composting; and the economic barriers and incentives for environmentally friendly waste disposal options.

5.1 Facilities and infrastructure for waste composting

Currently composting at a municipal level treats mainly plant waste. Even the composting of domestic waste can be seen as problematic due to potential contaminants. A 1992 review of waste management options identified the potential for composting but also a distinct lack of facilities [21]. A 2003 review highlighted a lack of progress in this field [22] and for composting to be applied on a large scale to be able to deal with building waste a fundamental change in the government's approach to waste disposal would be necessary.

5.2 Economic barriers and incentives for environmentally friendly waste disposal options.

In addition to adequate facilities the economics of composting needs to be convincing. In their 2001 report on the Landfill Tax, *Resource productivity, waste minimisation and the landfill tax*, the ACBE concludes that while the Landfill Tax has had some success at increasing the amount of inert waste recycled on site, it has had little success at reducing waste taxed at standard rates and increasing recycling. The report recommends an increase of the tax in line with other European countries, which benefit from far higher recycling rates [23].

While in the UK waste minimisation within the construction industry can prove cost-effective. A comprehensive approach to waste minimisation that includes reduced disposal costs of segregated waste as well as reduced costs associated with new material purchase, delivery and handling can save the house building industry as much as £1400 per house unit [24]. But when it comes to selecting a disposal method, composting is the most expensive, with the combined collection & gate cost per tonne of £42-£103 comparing poorly with landfill (£19-£29), incineration (£30-£40), paper and board recycling (£19-£25), plastics recycling (£2 £5), not to mention recycling of aluminium where a tome of waste is worth £411- £338 [25].

6 Conclusion

Numerous barriers exist to creating a building industry that makes use of biodegradable materials and composting as a means of reducing the end of life building waste. Nonetheless, the study identified potential for significant reductions in non-biodegradable waste through the use of biodegradable materials. It also concludes that constructing a virtually 100% biodegradable building is technically possible and implementing such technologies into mainstream construction is to some extent feasible.

To bring biodegradable buildings into mainstream construction more research is required in material sciences to bring down costs and reassure buyers of the materials' performance. Also an attitude change is needed. Currently there is a perception barrier: natural materials are sometimes associated with old fashion and backwards. But as the culture that views humans as stewards of the environment spreads and is reinforced by the trends of downshifting, back to nature and even slow food, people's perception will change in favour of natural materials making biodegradable mainstream building possible.

It is worth noting that natural biodegradable materials are also associated with other benefits such as creating healthy living environment and providing a low embodied energy structure with a low overall ecological footprint. Biodegradable plant-based materials can also prove cost-effective and particularly in developing countries have the potential to make a significant contribution towards providing low cost housing.

Perhaps a realistic approach to achieve the overall aim to bring closed material cycle building into mainstream construction is to use a combination of both recyclable and biodegradable materials.

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