DESIGN FOR DECONSTRUCTION LESSONS FROM THE MANUFACTURING INDUSTRY

Chinwe Isiadinso[1], C.J. Anumba[1], J. El-Rimawi[1] and T. Bhamra[2]

[1] *Department of Civil and Building Engineering, Loughborough University, Loughborough, Leicestershire, LE11 3TU, UK*
[2]*Department of Design and Technology, Loughborough University, Loughborough, Leicestershire,LE11 3TU, UK*

The concept of sustainable development is evolving within the construction industry. The industry through its activities (such as construction, operation, maintenance, and demolition of buildings) generates waste and pollution in the built and natural environment. The concept of deconstruction is becoming recognised as an aspect of sustainable construction and one of the ways to address some of these environmental issues. The manufacturing industry has made considerable progress in tackling environmental issues through Design for Environment (DFE) and Design for Disassembly (DFD). The construction industry can benefit by learning from the techniques/methods used to implement DFE and DFD in the design process of manufactured products. This paper discusses the emerging concept of design for deconstruction in the construction industry and compares it with design for disassembly in the manufacturing industry. It identifies the key elements of design for disassembly in the manufacturing industry and explores which of these can be adapted or adopted to facilitate the integration of Design for Deconstruction into the conventional design and construction process. It is expected that this will assist in the development of an appropriate tool for use by designers at the early design stage of a building.

Keywords: construction, deconstruction, design for deconstruction, disassembly, manufacturing

INTRODUCTION

In the last few years, the concept of sustainability with the three broad themes of social, economic, and environmental issues has become topical in both construction research and industry practice. The environmental theme of sustainability covers both the built and natural environment. The construction industry is responsible for developing the built environment. Through its activities such as erecting a building, the industry have negative impacts on the environment, consume a large amount of natural resources and generate volumes of waste. The resulting effects from these activities on the environment such as pollution, waste and depletion of natural resources are now issues for the industry to address. For example, it is estimated that in the UK over 70 million tonnes of waste is generated annually by the industry (CIRIA, 1999). The main challenge for the industry is to respond by implementing sustainable solutions which would assist in reducing the negative impacts of its activities on the environment. Figure 1 below is an illustration of how the industry is working towards achieving sustainability in construction.

[1] C.isiadinso@lboro.ac.uk

Isiadinso, C, Anumba, C.J, El-Rimawi, J, and Bhamra, T (2006) Design for deconstruction lessons from the manufacturing industry. *In:* Boyd, D (Ed) *Procs 22nd Annual ARCOM Conference,* 4-6 September 2006, Birmingham, UK, Association of Researchers in Construction Management, 937-946.

In order to address these environmental issues in a sustainable way and embrace a holistic approach to solving the problem, the life cycle of a building is often taken into consideration. A building during its life cycle undergoes design, construction, use, maintenance, demolition and finally disposal. Instead of disposal or demolition which can have a negative impact on the environment, deconstruction of the building should be encouraged. Deconstruction is the selective dismantling or disassembly of building structures to facilitate the efficient reuse or recycling of components and building materials in new construction and minimise waste (Guy and Shell, 2002; Durmisevic and Brouwer, 2002; Dantata *et al.*, 2004). The concept of deconstruction amongst other solutions in achieving sustainable development has been recognised as a way to address environmental issues in the design and construction process (Kibert, 2003).

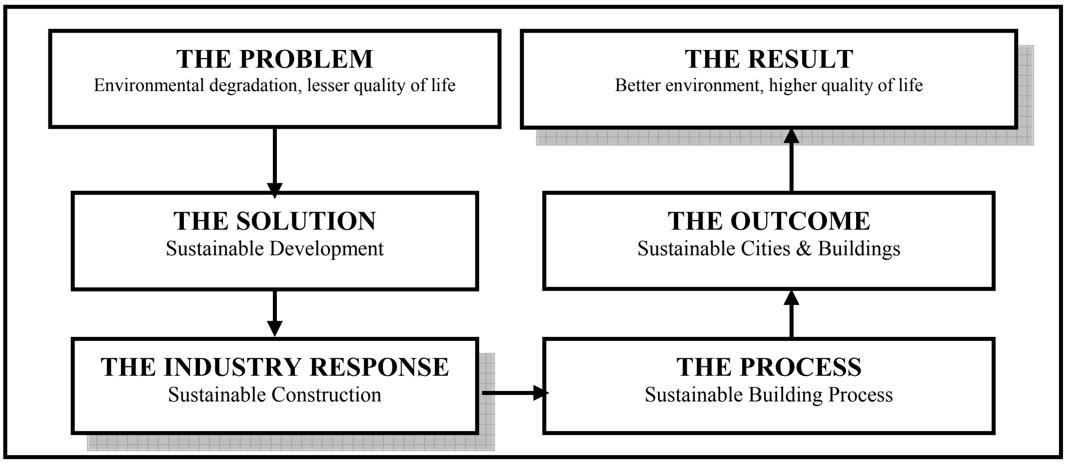

Figure 1: A simplified road map for sustainable construction (Huovila and Koskela, 1998)

With the growing pressure from consumers and legislation for environmental considerations, there is now a need for the industry to increasingly consider the recycling and reuse of materials/components used in building design and construction. Integrating the concept of deconstruction into the construction project delivery process can assist the industry to better reuse and recycle building materials and achieve a sustainable environment. One of the approaches taken by industry to facilitate the adoption of deconstruction is designing a building with the intention of disassembly instead of demolition at the end of its useful life. This concept is known as design for deconstruction. Its purpose is to assist the industry to address environmental issues and also reduce disposal costs by reusing and recycling greater proportions of building components/materials.

In contrast to the construction industry, the manufacturing industry has in the last few decades successfully implemented Design for Disassembly (DFD) as well as Design for Environment (DFE) in its production process. These two concepts are similar and based on the same principles as outlined for design for deconstruction. In producing buildings, the construction industry can adopt some of the principles and techniques successfully used in implementing DFE and DFD in the manufacturing industry as they already have a head start.

The purpose of this paper is to explore the concept of design for deconstruction in the construction industry and what lessons can be learnt from the manufacturing sector. It starts with a brief comparison of buildings and manufactured products, and outlines the key objectives of design for deconstruction. It then reviews DFD and DFE in the manufacturing industry and also considers how they can be adopted or adapted to facilitate the process of design for deconstruction in the project delivery process.

COMPARISON AND SIMILARITIES BETWEEN BUILDINGS AND PRODUCTS

A building can be likened to a complex product, as it comprises several different components and materials, which have different lifespans and uses. Unlike consumables or manufactured products, buildings are perceived to be unique due to their individuality, longevity, and method of assembly. They are often designed and expected to have a longer life than most manufactured products such as cars, machines and electrical goods. The lifespan of a typical building would usually range from 50 to 100 years and sometimes beyond. In addition, there is also a general perception that buildings should be durable and a significant artefact compared to consumables. Amongst the different groups of consumables today, one group is given the name complex goods. Products of this group require special design in connection with their end-of-life management (Bellmann and Khare, 2000). The characteristics of complex goods are similar to buildings as they comprise of several different components/materials and have relatively long life span and use. Some examples of complex goods are electro-technical goods (domestic electronics, appliances, measuring instruments, etc) machines and vehicles (cars, power units, aircraft, etc).

The process and approach taken by manufacturers to design and produce these products can be comparable to the design and construction process of buildings. The similarities between the two industrial processes arise from the fact that to produce a building or a complex product the following conventional steps are taken to develop the end product (see Fig 2).

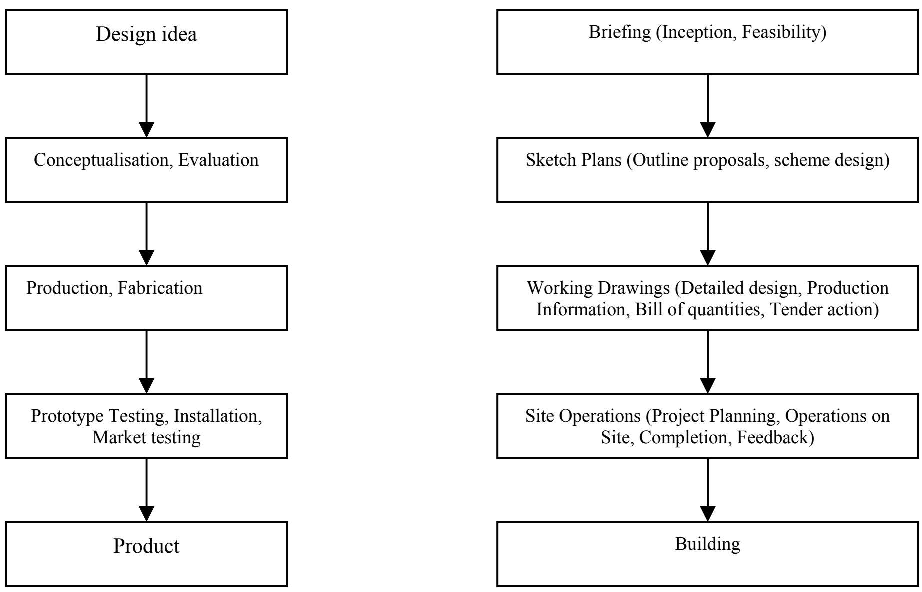

Figure 2: An illustration showing the similarities in the development steps of buildings and complex products

Although there are several similarities between the construction and manufacturing process, most stakeholders involved in the construction process believe that buildings are usually project based in nature and do not have the same principles and techniques as the manufacturing process (Crowley, 1998). Also, the construction process can be seen as fundamentally a different kind of production when compared to the manufacturing process as it often involves: one-of-a-kind nature of projects; site production; and temporary multi-organisation at a given time (Ballard and Howell, 1998).

In spite of the differences in production, most buildings generally have a relatively short lifespan like complex products as a result of the following factors: changing cultural expectations, economic conditions regarding land use, environmental impacts and technological obsolescence of some building components/materials (especially with regard to energy-efficiency) are lessening the life span of most buildings. This, in turn, encourages waste which is associated with construction activities such as demolition, refurbishment, operation/maintenance and disposal. The negative impacts these activities have on the environment, is driving the construction industry to reconsider the removal of components/materials and disposal of buildings, which have social, economic and environmental consequences (Guy and Shell, 2002). Since the manufacturing industry is already addressing environmental issues of its products through DFD and DFE, it is important for the construction industry to examine those approaches that are applicable to the design and construction process of a building.

DESIGN FOR DECONSTRUCTION

Deconstruction as both a concept and an area of research and development within the construction industry is evolving as a result of the growing awareness and need for sustainable development. The process of demolishing a building often involves selective dismantling of building components and materials for possible reuse or recycle. This activity, known as “soft stripping of a building”, is carried out before all forms of demolition (renovation, refurbishment, partial or total demolition). It is usually the first stage of any demolition project after the initial planning stages of the process have been completed and services disconnected (Addis and Schouten, 2004). This aspect of the demolition process can be regarded as deconstruction - the disassembly of structures for the purpose of reusing the components and building materials. Deconstruction or disassembly of buildings can be described as a new approach to addressing waste in the disposal phase of the built environment rather than demolition, accompanied by maximising component reuse and materials recycling (Kibert, 2003).

The design of buildings that can easily be dismantled or disassembled is possible, except it poses a challenge to the construction industry in practice. The associated and perceived cost of dismantling a building with traditional construction methods has, over the years, determined the very small scale of the deconstruction process. In order to consider an appropriate technique to dismantle a building the type of materials and components used and how they are fixed or assembled is significant. Although materials and components vary in characteristics, composition and usage, the methods by which they are assembled are similar. Within the construction industry there are various methods which are available to assemble a building. These methods include bolting, welding, screwing, nailing and bonding for materials and components such as timber, steel, partitions, concrete, tiles, floor boards and ceilings. Most of the methods employed to assemble these materials and components have their benefits and drawbacks to the process of deconstruction (Guy and Shell, 2002).

Macozoma (2002) has defined design for deconstruction as designing a building and its components with the intention of managing its end-of-life more efficiently. He argues that one of the key determinants of successful building disassembly is the ability and ease with which components and materials can be recovered. Pulaski *et al.* (2004) states that design for deconstruction increases the efficiency in a building's adaptability and encourages ease of disassembly, reduces the impact of pollution, and facilitates the recovery of building materials for reuse and recycling. These definitions suggest that the scope of design for deconstruction encompasses the life cycle of a building with its components/materials, design techniques, assembly and disassembly process, and environmental issues. Therefore the approach in which a building is deconstructed is significant as it would assist in sustainable construction practices. There are four approaches that can influence the design and specification of materials and building components to facilitate reuse and recycling after deconstruction:

1. Consider the whole life of a product or material;
2. Consider the potential of components for reuse;
3. Consider the process of deconstruction when designing components and buildings;
4. Consider the ownership of buildings and their components (Addis and Schouten,2004).

Design for deconstruction is a new challenge for the construction industry since it entails considering what happens to a building and its components/materials at the end of its useful life. To encourage and implement design for deconstruction, the industry would need to reconsider its current practices and adopt deconstruction principles. The manufacturing industry is already designing products with environmental and disassembly considerations, and so parallels can be drawn from their current practice.

DESIGN FOR DISASSEMBLY (DFD) AND DESIGN FOR ENVIRONMENT (DFE)

Due to environmental concerns in recent years, manufacturers of complex goods such as cars are beginning to consider the disassembly of products at the end of their life. The concept of DFD has emerged as a result of concerns for the environmental degradation that results during the disposal and manufacturing of products. Furthermore, eco-design and design for environment (DFE) are terms formulated in the manufacturing industry with the aim of integrating environmental considerations into product design and development. They both involve life-cycle thinking, which means the integration of life-cycle considerations into product design.

Design for Disassembly (DFD)

The concept of DFD evolved from Design for Assembly (DFA) which assisted the manufacturing industry to facilitate assembly activities, reduce costs, and simplify the production process in the late 1970s (Kuo *et al.* 2001). With the remarkable increase of used products being disposed, the concept was transferred to the disassembly of products. DFD can be described as the need to design for easy disassembly and component recycling in order to reduce total life-cycle cost (Kuo *et al.* 2001). Disassembly includes two main tasks: dismantling of the components which should be removed from the product (car) due to environmental demands and dismantling of valuable parts according to customer (market) demands for recycled products.

DFD has also evolved as a method of analysis to assist with the impact of design in the overall life-cycle thinking of products. Therefore the main principle of DFD is to ensure that a product's parts can be easily reused, re-manufactured or recycled at end of life instead of disposed. The following have been identified as DFD principles in product manufacturing:

Designing for ease of disassembly, to enable the removal of parts without damage;

Designing for ease of purifying, to ensure that the purifying process does not damage the environment;

Designing for ease of testing and classifying, to make it clear as to the condition of parts that can be reused and to enable easy classification of parts through proper markings;

Designing for ease of reconditioning, as this supports the reprocessing of parts by providing additional material as well as gripping and adjusting features;

Designing for ease of re-assembly, to provide easy assembly for reconditioned and new parts (Dowie-Bhamra, 2005)

DESIGN FOR ENVIRONMENT (DFE)

Design for environment (DFE) is one of the many sustainability strategies for design and it is also known as Eco-design (Ljungberg, 2005). DFE is defined as the systematic consideration of design issues during new production and process development, linked with environmental safety and health over the life-cycle of a product (Fiksel, 1993). DFE is about recognising and implementing the following strategies: use of materials with low environmental impact; choosing cleaner production processes; avoiding hazardous and toxic materials; maximising efficient use of energy both for production and when product is in use; and designing for waste management and recycling (Ljungberg, 2005). It serves as a practical way to address environmental impacts associated with a manufacturing a product. The Life Cycle Assessment (LCA) methodology is used as a framework by designers to implement environmental considerations from conceptual design through to the disposal stage of the product. Other approaches used by product designers, which recognise environmental impacts, include: design for recycling, design for disposability, design for service, design for energy recovery, etc (Ljungberg, 2005). These design approaches are linked and are all part of designing for a sustainable environment.

A CASE FOR ADOPTING DFD AND DFE IN CONSTRUCTION

Over the years several research works have been carried out within the construction industry with regards to the adoption of techniques, concepts and principles of the manufacturing industry (Fox *et al.*, 2001). There is evidence that the construction industry have been embracing manufacturing principles and techniques to produce and construct buildings. For example in Japan, a two-way learning between the manufacturing and construction sectors has resulted in industrialised housing through successful adoption of factory production methods and techniques to develop houses (Gann, 1996). There is a recognition within the construction industry that adopting these practices from the manufacturing industry would not necessarily resolve all issues encountered during the design and construction process but would create the opportunity for the industry to adopt practices that are proven and have been successfully implemented in another industry sector. A number of construction practices that have their roots in the manufacturing sector include lean production, Just-In-time (JIT), business process re-engineering, mass production (Crowley, 1998).

Some of these manufacturing concepts and practices have been applied and adopted to traditional approaches to construction mainly based on cost, quality and time in the following ways:

Lean production – to encourage standardisation and develop an efficient production process resulting in cost savings, value and time;

Logistics and supply chain management – to increase efficiency in the process of construction through coordination and communication between all parties involved in a project (especially as it relates to delivery, handling and installation of materials/components);

Mass customisation – to meet varying demands of customers and achieve efficiency with optimal design (Lessing et *al.*, 2005).

Examples of these concepts in construction practice are often found in affordable housing projects by governments or private developers. Apart from these concepts, the construction industry has in the past adopted a number of approaches based on manufacturing principles to assemble buildings. These approaches are known as 'industrialisation in construction'. Industrialisation in construction has been approached in the following ways:

Prefabrication - is the production of components in factories for assembly on site with the aim of reducing cost and increasing the speed of the construction process;

Open building. - encourages flexibility for architectural designs, allowing easy alterations during use, future changes and modernisation of buildings;

Offsite production - though similar to prefabrication involves production of whole building systems in the factory to be assembled on site;

System building – involves a more extensive use of prefabricated components with quality control, working together with manufacturers, the use of programming methods for construction sequencing and documentation of the process(Gann, 1996);

Standardisation. - described as the extensive use of components, methods and processes to achieve regularity, repetition and predictability in construction (Gibb, 2001).

The development of each concept has been influenced by manufacturing techniques/methods and the need to continually improve the project delivery process in construction.

Although industrialisation in construction has worked very well in some housing and office complex projects, it is important to recognise that there are limits to which these techniques and methods can be applied to other types of buildings and the project delivery process in construction. These limitations to the design and production of buildings are as a result of external factors such as a building's location, prevailing climatic conditions and varied stakeholder involvement during the design and construction phase. Also, manufactured products usually have standard design and methodologies to assist product designers unlike construction where each building architectural design tends to be unique. In spite of these limitations, the construction industry would benefit from adopting DFD and DFE methods/techniques, as both concepts have emerged as a result of concerns for environmental degradation during the disposal and production of complex products. Both concepts in addition to design for deconstruction, are focused on designing and manufacturing products with the intention to minimise waste and encourage reuse and recycling of materials. Since the construction industry is faced with the same environmental issues of building disposal, depletion of natural resources during construction and the need to minimise waste, it becomes necessary for the industry to adopt the principles and techniques of these concepts.

LESSONS FOR THE CONSTRUCTION INDUSTRY FROM PRODUCT DISASSEMBLY

There are real lessons that can be learnt from the manufacturing sector with regard to its approach in addressing environmental issues facing the construction industry. Gibb (2001) argues that although there are lessons to be learnt from the manufacturing sector, most products are mobile whilst buildings are fixed to the ground. Gann (1996) makes a similar point, stressing that there are limits to which manufacturing techniques derived from the car industry can be applied to manage the assembly of wide varieties of component parts needed to produce complex customised products such as buildings.

The construction industry however has a lot of lessons to learn from product industries (such as the automobile and electrical) as the industry lags behind in efficiency related to material consumption, reuse and recycling. The lessons learnt can facilitate the implementation of deconstruction into the design and construction process of buildings. The following lessons can be learnt and adopted in the construction industry:

Implementation of standards (such as ISO 14001) that would encourage the integration of the deconstruction process into conventional construction practices.

Forming partnerships with manufacturers and suppliers of building materials that will encourage the re-manufacture of used materials.

Encouraging the use of recycled materials by specifying these materials in new construction design

Adopting the life-cycle assessment concept into the early stages of a building design

SUMMARY AND CONCLUSIONS

When buildings approach the end of their useful life or require refurbishment, the decision to totally or partially demolish them is becoming very significant. This significance is based on the vast quantities of waste and pollution that is produced during construction activities. For the industry to be environmentally responsible, it would need to incorporate the deconstruction process, which is an aspect of sustainable construction. This paper has identified the underlying issues of designing with consideration for the environment through approaches such as design for deconstruction, DFD and DFE in the construction and manufacturing industries. It also examined how the construction industry can adopt and develop the concept of deconstruction by learning lessons from the manufacturing sector. Industrialisation in construction has shown that it is possible to adopt techniques and methods from the manufacturing industry and apply it to the construction industry. For the principles of deconstruction to be implemented in the construction process through design for deconstruction, lessons from DFD and DFE in the manufacturing sector can be incorporated through the relevant context of environmental solutions such as ISO 14001.

To successfully adopt design for deconstruction into the conventional design and construction process, the industry would require to consider the following:

- The techniques and methods used to assemble and construct buildings.
- The use of components that require screws and bolts to assemble instead of adhesives since they can easily be dismantled.
- The design of flexible and adaptable buildings that can easily be transformed for a new use other than the original purpose.
- Specification of components with modular and standard measurements to encourage reuse or recycling of the materials.
- The need to create markets and establish legislation within the industry that will support the use of recycled materials.

REFERENCE

Addis, W. and Schouten, J. (2004) Design for deconstruction. Principles of design to facilitate reuse and recycling. C607 London:CIRIA.

Ballard, G. and Howell, G. (1998) What kind of production is construction? Theory. *Proceedings IGLC-6*, August 1998, Guaruja, Brazil.

Bellmann, K. and Khare, A. (2000) Economic issues in recycling end-of-life vehicles,*Technovation*, **20,** 677-690.

Crowley, A. (1998) Construction as a manufacturing process: Lessons from the automotive industry, *Computers and structures*, **67,** 389-400.

Durmisevic, E. and Brouwer, J. (2002) Design aspects of decomposable building structures, design for deconstruction and materials reuse. *Proceedings of the CIB Task Group 39* - Deconstruction Meeting 9 April 2002, Karlsruhe, Germany

Dantata, N., Touran, A., and Wang, J. (2004),An analysis of cost and duration for deconstruction and demolition of residential buildings in Massachusetts. *Resources Conservation and Recycling*, **44**, 1-15.

Fiksel, J. (1993) Design for the Environment: An integrated systems approach, *IEEE International symposium on electronics and the environment*, Virginia:IEEE.

Fox, S., Marsh, L. and Cockerham,G. (2001) Design for manufacture: a strategy for successful application to buildings, *Construction Management and Economics,***19** 493-502.

Gann, M.D. (1996) Construction as a manufacturing process? Similarities and differences between industrialised housing and car production in Japan. *Construction Management and Economics*, **14,** 437-450.

Gibb, .A. G. F. (2001) Standardisation and pre-assembly – distinguishing myth from reality using case study research", *Construction Management and Economics*, **19,** 307-315.

Guy, B. and Shell, S. (2002), Design for deconstruction and materials reuse.Design for deconstruction and materials reuse. *Proceedings of the CIB Task Group 39* - Deconstruction Meeting 9 April 2002, Karlsruhe, Germany

Huovila, P. and Koskela, L. (1998) Contribution of the principles of lean construction to meet the challenges of sustainable construction, implementation. *Proceedings IGLC*-6,August 1998, Guaruja, Brazil.

Kibert, C. (2003) Forward: Sustainable construction at the start of the 21st Century. Special issue article in: *The Future of sustainable construction*: http://www.bcn.ufl.edu – special issues catalogue. Accessed July 2005.

Kuo, T–C., Huang, S.H. and Zhang, H-C. (2001) Design for manufacture and design for 'X': concepts, applications, and perspectives. *Computers & Industrial engineering,* **41** 241–260.

Lessing, J. Stehn, L. and Ekholm, A. (2005) Industralised housing: definition and categorisation of the concept, Prefabrication, Assembly and Open building. *Proceedings IGLC* -13, July 2005, Sydney, Australia.

Ljungberg, L. Y. (2005) Materials selection and design for development of sustainable products", *Materials and Design*. Available online 1 December 2005.

Macozoma, D.S. (2002) Understanding the concepts of flexibility in design for deconstruction. Design for deconstruction and materials reuse. *Proceedings of the CIB Task Group 39* - Deconstruction Meeting 9 April 2002, Karlsruhe, Germany.

Pulaski, M., Hewitt, C., Horman, M., and Guy, B. (2004), Design for deconstruction, *Modern steel construction*, June 2004

Storey, J. (2002) Reconstructing deconstruction, Design for deconstruction and materials reuse. *Proceedings of the CIB Task Group 39* - Deconstruction Meeting 9 April 2002, Karlsruhe, Germany.

ISO 14001(Environmental Management Guide):http://www.iso14000-iso14001-environmental-management.com/