Design for Disassembly

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Abstract

One of the main obstacles to building material reuse is the difficulty in separating materials and components from the building. Design for disassembly is a useful strategy that can be applied to varying extents to increase the future rates of material and component reuse. Buildings have been designed for disassembly in the past and there are valuable lessons to be learned from those examples.

Key words
design, disassembly, recycle, reuse, waste management

1.0 Introduction

In our current industrialised society, the usual practice for dealing with unwanted buildings is to remove anything of immediate value, demolish the rest, and dump it all into the ground. It is now becoming more apparent that this practice cannot be sustained, either economically or environmentally.

Our culture is changing more and more rapidly, but for the most part we are still making buildings that are intended to be permanent. We seek continuity in our built environment and many designers practice in the hope that their buildings will last for ever as monuments to our time. The reality, however, is that very few buildings will even outlive their creators without undergoing major renovation, refurbishment, or even total demolition.

This lack of permanence is a result of building obsolescence, and this obsolescence is more often the result of cultural change rather than of physical deterioration or failure. Buildings designed and built thirty years ago can no longer meet the requirements of our society today. We now have different expectations of our built environment. This results in the adaptation of buildings for reuse, or their demolition for replacement, and this in turn results in large amounts of material and component wastage.

There are two possible ways to attack this problem. One is a cultural change, the other a technological change. Any realistic attempt at achieving major improvements will require some form of both. What this paper presents are some thoughts primarily on the topic of technological change, but this in itself will only be possible through cultural acceptance of a new approach to construction and material use. Minor technological changes can however be easily implemented at the design stage to help to improve the possibility of future reuse.

The strategy of design for disassembly has been widely investigated in industrial and product design and many cars and computers are now designed for disassembly to allow for future component and material recovery. Similar strategies could easily be adapted to the building industry to facilitate the future reuse of materials and building parts.
2.0 Waste

Australians are now disposing of millions of tons of solid waste per year, up to a third of which is construction and demolition waste (Craven et al. 1994). There is an established industry dealing with the reuse and recycling of materials and components from residential demolition. In fact up to 90% of building materials from demolished houses can, and often are, reused. These figures do not however translate to commercial and industrial building demolition. As little as 11% of demolished CBD office building materials are recovered for reuse. While some of the remainder is reprocessed into lower grade materials the majority is dumped into landfills (Salomonsson & MacSporran 1994).

One of the main reasons for these alarmingly low rates of reuse is the difficulty in separating components and materials from the remainder of the building. This difficulty makes the process either totally impractical or simply too slow to make recovery of components economically viable. The remaining solution of demolition leaves most of the materials broken and contaminated and unsuitable for anything other than dumping.

This dominant mode of operation can be seen as a one way process. This process has several important steps; raw materials are extracted from the natural environment, they are processed into useable materials, materials are manufactured into components, components are assembled into buildings, the buildings are used, the buildings are refurbished, when they can no longer be refurbished to a high enough standard the buildings are demolished, and finally the materials are disposed of as waste. This cradle to grave approach sees materials live a single life then die (see Figure 1).

![Figure 1. The common scenario of a cradle to grave flow of resources in the built environment](image)

The problems with this scenario and the resulting high rate of waste can best be illustrated using a life cycle assessment matrix. Such a matrix plots possible environmental impacts against the various life cycle stages of a project (those stages shown in Figure 1). For a generic building project, using common building practice, there will be negative impacts at most stages of the process. There will however be some areas of significant impact, especially the impacts of energy use and resource depletion. These significant impacts can be plotted on a life cycle assessment matrix to illustrate the areas of major concern (see Figure 2).
3.0 A new model

This common cradle to grave pattern of resource use is not the only option. It is possible for materials, components, and whole buildings to actually have several lives before they must be retired as waste. There are basically four possibilities for reincarnation in the built environment (see Figure 3):

- relocation and reuse of an entire building - this may occur where a building is needed for a limited time period but can later be reused elsewhere for the same or similar purpose.
- reuse of components in a new building or elsewhere on the same building - this may include cladding element or internal fitout elements that are of a ‘standard’ design.
- reprocessing of components and materials into new components - this will involve materials or products still in good condition being used in the manufacture of new building components.
- recycling of materials into new materials - this will involve used materials being used as a substitute for raw materials in the processing of manufactured materials.

We can now look at the environmental impacts such an alternative scenario would have by using the life cycle assessment matrix (see Figure 2). It is quite apparent that the only negative impacts that will not be significantly reduced are those that occur at the stage of building use. A design for disassembly strategy can greatly reduce resource depletion and species and habitat loss, it can reduce energy use and pollution production, and it can also have significant effects on social and human health issues.

The scope of these impact reductions will depend on the extent of reuse that is achieved. For example the scenario of total building reuse will drastically reduce energy use and resource depletion, whereas the scenario of materials recycling will reduce resource use but will still require significant energy use for reprocessing and manufacture.
4.0 History of disassembly

While these strategies for reuse are not part of common building practice, it has not always been so. There are numerous historic, and recent, examples of building that were designed for disassembly to allow materials, components, or whole buildings to be reused or recycled. A study of these examples reveals interesting lessons that may have relevance today.

The ancient form of the tent is a good example of careful consideration of resource use in a way that allows the components to be disassembled for relocation, replacement, and maintenance. Tents typically use separate compressive frames and tensile membranes to create a stable structure that can be easily and quickly taken apart by the user. The light weight of the materials and the size of the components are important features of the design.

The reuse of timber members in ‘permanent’ buildings has similarly been common practice in the distant past. In Europe, in the Middle Ages, the scarcity of suitable building timber led to the regular reuse of large members. The common practice at the time of using large timber pegs to connect beams allowed for the disassembly of buildings when they were no longer required so that materials could be reused. This technology was not limited to Europe. Traditional timber domestic architecture of Japan utilises similar jointing technology to create connections that can be altered in the future. In this system a primary frame is built to suit structural requirements, then a secondary frame is built to suit spatial requirements. This allows the secondary frame to be easily altered to suit the changing requirements of the inhabiting family without affecting the structural frame and without the wastage of building materials that other technologies produce (Itoh 1972).

The technology of disassembly in timber houses reached a peak in the Nineteenth Century in Great Britain. At this time Britain was exporting prefabricated houses and other buildings to British colonies in other parts of the world. This technique allowed the assembly of high quality buildings in places where suitable materials and skilled labour were often scarce. When Governor Phillip arrived in Sydney Cove in 1788 he brought with him a prefabricated portable cottage with a timber frame and canvas roof and walls (Herbert 1978, p.5).

An Australian newspaper advertisement of 1837 clearly outlines the benefits of the houses manufactured by John Manning of London which were “manufactured on the most simple and approved principles . . . complete for habitation in a few hours of landing. They may be taken

![Diagram of the four possible reincarnation scenarios for resources in the built environment](image)
to pieces and removed as often as the convenience of the settler may require" (Herbert 1978, p.11). The Manning portable cottages came in standard designs of from one to four rooms. Cottages were constructed of timber posts which were grooved to house interchangeable wall panels. The frame and panels were held together using a small number of bolts and could all be assembled or disassembled using a spanner.

Eventually, as some British colonies developed their skill base, they started exporting portable cottages themselves. Some portable cottages in Australia were supplied with Chinese characters marked on the members (Lewis 1993), assumedly as instructions or codes for the assembly process.

While timber was a common material for portable cottages it was not the only one. With the developments of corrugated sheet steel and the hot dip galvanising process, metal buildings became common due to the light weight of the sheets and their ease of handling. Some such cottages are still in existence in Melbourne. Experiments were also carried out with other materials including paper with waterproof coatings.

Still in the Nineteenth Century, but at the other end of the size scale, there are other interesting examples of buildings designed for disassembly. In 1851 the Crystal Palace was built to house 'The Great Exhibition of the Works of Industry of All Nations'. This temporary trade fair required a temporary home, and the design by Joseph Paxton allowed for the disassembly and relocation of the building after the exhibition. The entire building was based on a structural grid that was generated from the largest piece of glass available at the time. On this grid a framework of cast iron columns was set out which were interconnected with trusses of iron and timber. These trusses were slotted into flanges in the columns and held in place with timber or iron wedges hammered into place. So successful was this design that the building was easily disassembled, relocated and actually expanded on a new site after the exhibition (Peters 1996). The open system of constructing the building allowed an alternative arrangement of the standard parts so that the building could be altered with very little modification to the components.

Temporary buildings designed for use in times of war offer a wide range of examples of disassembly for reuse. One of the more widely used examples is the Nissen Hut. This barrel vaulted building made of corrugated sheet steel and timber could be assembled by four men in just four hours using nothing more than a spanner (Mallory and Ottar 1973). This was possible due to the simple components, the small number of different components, the size of the components, and the simple assembly process that needed only everyday tools.

Buckminster Fuller designed temporary portable buildings for war time use that utilised the mass production technology of munitions factories. After the war, Fuller also had ideas for the use of such technology to make prefabricated houses. He proposed that these Dymaxion houses would be rented to their occupants like a product that would be serviced, repaired, replaced, and finally recycled by the manufacturer (McHale 1962). The Dymaxion house was never fully developed, but Fuller’s later design for the Wichita house was built based on similar principles. It was intended to be mass produced from standard components, each of which would weigh no more than five kilograms. The house would arrive at its site packed in a single steel cylinder and could be assembled by six people in just one day (Kronenburg 1995).

More recently there have been a number of innovative thinkers that have proposed designs for buildings that could be disassembled. These include Cedric Price, the members of Archigram, and the members of the Japanese Metabolism movement. All of these architects developed schemes that allowed parts of the building to be disconnected from the whole for replacement without interrupting the remainder of the building. Many of these schemes, such as the Plug-in City by Archigram, arranged building parts according to a hierarchy of use such that parts of the building that would require the most frequent maintenance or replacement would be most accessible (Cook et al. 1972). While most of these ideas never left the drawing board, the international Expo of 1970 in Japan did allow some of these principles to be tested at full scale and the resulting Capsule House and Takara Pavilion were successfully
constructed. Like the traditional Japanese timber house, these buildings allowed for the easy removal of parts without interrupting the whole.

While these historic examples, and numerous others, were designed for disassembly for different reasons, the technologies developed for them show many common trends. These trends highlight the possibility of various strategies that will help us to design for disassembly. These strategies have tremendous possibilities in light of current concern for materials reuse. Most of these ‘forgotten’ technologies have not found their way into common building practice, which is now so heavily concerned with speed and short term financial gain. Most of these ideas are not however difficult to incorporate into our current construction practice, in fact most of them are perfectly compatible with good common sense.

5.0 Recommendations

What then can designers, architects, and engineers do to help increase the rates of material reuse through design for disassembly. Firstly the designer must establish the level of disassembly that is appropriate. This will be related to the four possibilities of reincarnation (see Figure 3). Ideally buildings would be designed for component reuse or total relocation, but within the current dominant methods of building procurement it may be more realistic to expect to target the scenarios of component reprocessing and material recycling.

Each of the possible reincarnation scenarios can be addressed with certain design strategies that will help to improve the future potential for disassembly. Many of these strategies are common to all the scenarios but some are only appropriate for the higher level strategies of component reuse or building relocation.

While design for disassembly is primarily a design issue, and as such will be of most relevance to designers, there are factors outside of the design process that will also help improve the rates of reuse. As such the strategies presented here will be relevant to many different participants in the building process.

Strategies for material recycling

- Use recycled materials – increased use of recycled materials will encourage industry and governments to investigate new technologies for recycling, and to create a larger support network for future recycling and reuse
- Minimise the number of different types of materials – this will simplify the process of sorting materials on site and reduce transport to separate reprocessing plants
- Avoid hazardous or toxic materials – this will reduce the potential of contaminating materials that are being sorted for recycling and will also reduce the potential for human health risks during disassembly that may make recycling a less attractive option
- Make inseparable sub assemblies from the same material – this means that larger amounts of one material will not be contaminated by small amounts of a foreign material that can not be separated
- Avoid secondary finishes and coatings where possible – such coating may contaminate the base material and make recycling less attractive, where possible use materials that provide their own suitable surface finish or use separate mechanically connected finishes (some protective coatings such as zincalume will still be desirable in some situations for other reasons)
- Provide permanent identification of material types – many materials such as plastics are not easily identified and should have some form of non removable and non contaminating identification mark to allow future sorting of materials

Strategies for component reprocessing

- Minimise the number of different types of components – this will simplify the process of sorting on site and make the potential for reprocess more attractive due to the larger quantities of same or similar items
• Use a minimum number of wearing parts – this will reduce the number of parts that need to be removed in the remanufacturing process and thereby make reprocessing more efficient
• Use mechanical connections rather than chemical ones – this will allow the easy separation of components and materials without force, and reduce contamination to materials and damage to components
• Make chemical bonds weaker than the parts being connected – if chemical bonds are used they should be weaker than the components so that the bonds will break during disassembly rather than the components, for example mortar should be significantly weaker than the bricks

Strategies for component reuse

• Use an open building system – this will allow alterations in the building layout through the relocation of components without significant construction work
• Use assembly technologies that are compatible with standard building practice – specialist technologies will make disassembly difficult to perform and may require specialist labour and equipment that makes the option of reuse less attractive
• Separate the structure from the cladding, the internal walls, and the services – to allow parallel disassembly where some parts of the building may be removed without affecting other parts
• Provide access to all parts of the building and all components – ease of access will allow ease of disassembly, if possible allow for components to be recovered from within the building without the use of specialist plant equipment
• Use components that are sized to suit the intended means of handling – allow for various possible handling options at all stages of disassembly, transport, reprocessing, and reassembly
• Provide a means of handling components during disassembly – handling during disassembly may require points of connection for lifting equipment or temporary supporting devices
• Provide realistic tolerances to allow for movement during disassembly – the disassembly process may require greater tolerances than the manufacture process or the initial assembly process
• Use a minimum number of different types of connectors – standardisation of connectors will make disassembly quicker and require fewer types of tools, even if this result in the over sizing of some connections, it will save on assembly and disassembly time
• Use a hierarchy of disassembly related to expected life span of the components – make components with a short life expectancy readily accessible and easy to disassemble, components with longer life expectancy may be less accessible or less easy to disassemble
• Provide permanent identification of component type – similar to material identification, may use electronically readable information such as barcodes to international standards

Strategies for building relocation

• Standardise the parts while allowing for an infinite variety of the whole – this will allow minor alterations to the building without major building works
• Use a standard structural grid – grid sizes should be related to the materials used such that structural spans are designed to make most efficient use of material type
• Use a minimum number of different types of components – fewer types of component means fewer different disassembly operations that need to be known, learned or remembered – it also means more standardisation in the reassembly process which will make the option of relocation more attractive
• Use lightweight materials and components – this will make handling easier, quicker, and less costly, thereby making reuse a more attractive option
• Permanently identify point of disassembly – points of disassembly should be clearly identifiable and not be confused with other design features
6.0 Conclusions

These strategies are really a starting point in thinking about design for disassembly. As each building project is unique there can be no universal strategies that will always apply. Some of these design for disassembly strategies may be in direct conflict with other environmentally sustainable strategies. Like all attempts at improving our environmental performance, design for disassembly must be considered in a holistic way along with all the environmental life cycle factors that may affect a project.

Design for disassembly will not always be appropriate, but as buildings die younger and materials outlive them, we must consider ways to encourage material and component reincarnation.

7.0 References and further readings