Deconstruction - Closing the Loop
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DEVELOPING GUIDELINES FOR DESIGNING FOR DECONSTRUCTION

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SUMMARY

This paper presents the preliminary findings of a research project that attempts to produce a set of guidelines that can be used to assist in designing a building for easy future deconstruction, or to asses an existing building or design to determine how easily it might be deconstructed to recover materials.

Guidelines are being developed from industrial design practice, and from architectural technology employed in the past to achieve deconstruction. Guidelines can be used, along with an elemental breakdown of the building, to determine those parts of the building that will be easy to recover, and those that will not. If an environmental or financial assessment is also incorporated, a judgement can be made of those parts of a building that are worth recovering. In this way the deconstruction assessment can form part of a full life cycle assessment.

Guidelines are presented according to the level or scale of deconstruction that they assist in, such as recycling, reuse or relocation. The guidelines cover issues of material type, component design, fixing methods, information management and sustainment, and handling methods.

It is proposed that design for deconstruction can be implemented in the construction industry to improve the ease of future material and component recovery, and thereby increase the current rates of reuse and recycling.

KEYWORDS: Assessment; Deconstruction; Design for Disassembly; Guidelines;

INTRODUCTION

Current building practice, in industrialised countries, focuses primarily on the act of creation, the act of construction. At this time of construction little thought is given to the full life cycle of the building, especially in an environmental sense. Some consideration may be made of the materials being selected and the energy embodied in them, and concern is increasing over operational energy issues. Very few building designers, builders, and clients however, consider the end of life scenario. What will be done with the building after it has outlived its useful, or economic, life?

The most usual outcome is demolition, though deconstruction for recovery of materials and components is becoming increasingly common. One of the main barriers to such deconstruction however is that buildings are not designed to facilitate it. Most buildings are constructed in a manner that does not allow for disassembly as a simple reversal of assembly. Most buildings are cast-in-situ, built-in, or chemically bonded together in a way that prevents easy deconstruction.

Addressing this problem successfully requires both cultural and technological change. This paper presents some thoughts primarily on technological change to be implemented at the design stage of the building life cycle.

SOURCES OF INFORMATION

The strategy of design for deconstruction, or design for disassembly, has not yet become a major issue in the construction industry. There are however various sources of information on design for deconstruction that can be assessed for recurring principles. These principles can be developed into guidelines to be used by building designers to either develop building designs or to assess existing designs or buildings for future deconstruction.

Industrial Design

In the fields of industrial and product design, there is already a good understanding of the environmental benefits of recycling and reuse. The concept of Industrial Ecology has to some extent addressed the notion of reduced environmental impact through improved rates of material and component reuse to minimise waste. There are in fact many researchers who have already identified explicit guidelines for design for disassembly of industrial or manufactured products. Similarly numerous car, computer and household product manufacturers have already implemented the actual practice of design for disassembly.

A study of industrial design practice and research reveals a number of these design for disassembly guidelines that may have application in the construction industry [1]. These guidelines typically cover issues such as material compatibility, connection type, number of connections, handling facilitation, and information management.

Architectural Technology

While design for disassembly or deconstruction has not become a major part of main stream construction practice, there have been a considerable number of unique architectural efforts that have used such a technique. These buildings were originally driven by the same motivation that we face now, a need to conserve materials and energy.

Throughout history there have been many cases of buildings designed for disassembly either to allow for material reuse or for whole building relocation. From primitive huts to the Crystal Palace, and from traditional Japanese timber building to the schemes of Archigram and the Metabolists, there are valuable lessons in design for disassembly.

A survey of these historic examples reveals a number of common technological trends that suggest the possibility of developing guidelines for designing for disassembly in buildings [2]. These trends can be roughly grouped in to ideas about materials, structural systems, access, connection type, number of components, and appropriate technology.

Buildability

If the process of deconstruction is considered as the opposite of the process of construction, there may be some value in the study of making construction easier. If a building is easier to put together, it should be easier to take apart. The notion of buildability, making buildings easier to construct, has received some research attention.

This research has resulted in some explicit guidelines for buildability that should also assist in design for deconstruction [3]. These guidelines are primarily concerned with issues of handling, access, and prefabrication.

Environmental Sustainability
As well as guidelines for design for disassembly or deconstruction, guidelines for general environmental sustainability must also be considered. There may be cases where in attempting to allow for easier deconstruction, a greater environmental problem is created. Like all sustainability issues, these guidelines must be considered within a holistic view of the environment, both built and natural.

TYPE OF GUIDELINES

In order for the guidelines to be usable by designers there are several considerations on how they might be arranged and presented. The character and structure of the guidelines may effect their potential for application.

Guideline Character
It can be considered that there are three possible types of guideline. These can be arranged hierarchically from the broadest to the most specific [4].

- Behavioural Statements
- Performance Standards
- Prescriptive Guidelines

Behavioural Statements
These statements deal with values and general goals, they are the ideals of a certain community or group. In the context of building deconstruction such statements may include sustainable development goals such as:

- Reducing waste disposal and pollution
- Reducing greenhouse gas production
- Reducing energy consumption

Performance Standards
Standards are more explicit in their aim, they offer specific targets of achievement that will lead towards achieving behavioural statements. Performance standards that deconstruction can address may include:

- Increased rates of material recycling
- Increased rates of component remanufacture
- Increased rates of component reuse
- Increased building adaptability/relocatability

Prescriptive Guidelines

Guidelines then, offer the designer the most direction in achieving an aim, in this case deconstructability. These guidelines should be explicit in their aim without limiting the designer in their creativity to solve a problem. They should offer solutions of how to achieve performance standards.

Guideline Structure

In order for the guidelines to be applied most successfully they should be ordered in a way that assists the designer to use them. There are at least three possible ways of arranging a list of design for deconstruction guidelines, all used by researchers in industrial design, and each with its own advantages.

- By the environmental benefits they offer (with an applied weighting)
- By the chronological order of application
- By the technical benefits they offer

By Environmental Benefits

Many systems of building assessment utilise a system of categorising criteria according to their environmental benefits. Many of these systems utilise some form of weighting to prioritise those criteria [5]. There has also been research in developing weighted assessment criteria specifically for assessing the recyclability of building materials [6].

While such systems attempt to produce an orderly method of assessment for buildings and designs there are some problems with applying weightings to these criteria. It may be possible for a design to rate well overall but still have one totally inadmissible characteristic. In the case of deconstruction there is also the added problem that including a judgement or calculation of environmental benefit or damage adds another layer of complexity to the process. This added complexity might be confusing to inexperienced designers. In general the environmental benefits are very broad in concept and it may not be possible to isolate deconstruction matters from other sustainability issues.

By Chronological Order

There are several examples of guidelines, or performance criteria, that have been categorised according to the order in which the designer or other project manager might apply them. This form of categorisation has been used for industrial design and for general architectural assessment criteria. Such a chronology might be divided into categories or stages of *design, production, transport and erection, marketing, financing, and organisation* [7]. The stage of design might then be further divided into the stages of *conceptualisation, drafting, and detailing* [8].

In reality though the process of building design is not a simple linear process but a looped process where various options are designed and tested and the overall design progresses simultaneously on many levels. Due to this cyclical nature of the design process of buildings it makes little sense to try to arrange the guidelines in any sort of chronological order.

By Technical Benefits

It is also possible to order the guidelines by the technical benefits they produce. The technical benefits can be considered either in their scale or in their nature. Industrial design research into design for disassembly has produced many lists of guidelines that are sometimes classified according to the nature of specific technical benefits such as *ease of handling, ease of separation, predictable product configuration, and reduced variability* [9]. Similarly they might be classified according to the scale of application such as *materials, fasteners and connections, and overall structure* [10].

It is also possible to classify guidelines according to the scale or technical level of reuse, such as *material recycling, component remanufacture, component reuse, and building relocation* [11]. This is similar to the previous suggestion of the scale of application. In this way it may be possible to target a particular outcome, such as increased rates of component reuse, by giving priority to those guidelines that assist in that specific outcome.

On balance it should be noted that the complexity of the design process makes the development of any design tool or set of guidelines difficult. It may be however that a pattern of performance standards and prescriptive guidelines is a form that building designers are most familiar with. As such it would be most suitable to group guidelines according to the technical benefits that reflect the general performance standards, such as:

- increase material recycling
- increased component remanufacture
- increase component reuse
- increase building adaptability or relocation

Such a distinction also highlights the hierarchical nature of reuse being environmentally preferable to recycling. The strategy of component reuse will generally require much less processing energy and material input than the strategy of remanufacturing which again in turn requires less energy and material than the strategy of recycling, see Figure 1.

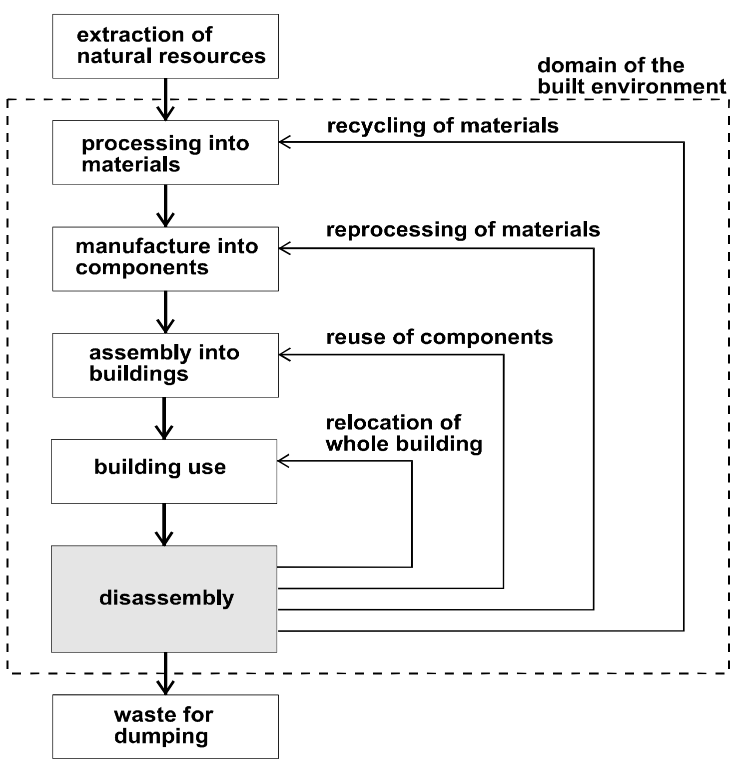

Figure 1 The four strategies for material reuse in the built environment

GUIDELINES FOR ARCHITECTURAL DESIGN FOR DECONSTRUCTION

Guidelines for design for deconstruction, developed from other information sources, can therefore be ordered to match this hierarchy of reuse, see Tables 1 to 4.

Table 1 Design for deconstruction guidelines for material recycling

No.	***Guideline***
M1	Use recycled materials – increased use of recycled materials will encourage industry and government to develop new technologies for recycling, and to create a larger support network for future recycling and reuse
M2	Minimise the number of different types of material – this will simplify the process of sorting on site and reduce transport to separate reprocessing plants
M3	Avoid toxic and hazardous materials – this will reduce the potential of contaminating materials that are being sorted for recycling and will also reduce the potential for human health risk during deconstruction
M4	Make inseparable subassemblies from the same material – this means that large amounts of one material will not be contaminated by small amounts of a foreign materials that can not be separated
M5	Avoid secondary finishes to materials – such coatings may contaminate the base material and make recycling more difficult, where possible use materials that provide their own suitable finish or use separable mechanically connected finishes (some protective finishes such as galvanising may still on balance be desirable for other reasons)
M6	Provide standard and permanent identification of material types – many materials such as plastics are not easily identifiable and should have some form of non removable and non contaminating identification mark to allow future sorting (ideally some form of bar code would be most suitable for fast identification, such a code could also provide information on place and date of production and structural capacity)

Table 2 Design for Deconstruction guidelines for component reprocessing

No.	***Guideline***
C7	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
C8	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
C9	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

C10	Where appropriate, 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

Table 3 Design for deconstruction guidelines for component reuse

No.	***Guideline***
R11	Use an open building system, a system where parts are more freely interchangeable and less unique to one application – this will allow alterations in the building layout through the relocation of components without significant construction work
R12	Use modular design – use components that are compatible with other systems both dimensionally and functionally
R13	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 more difficult
R14	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
R15	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
R16	Use components that are sized to suit the intended means of handling – allow for various possible handling options at all stages of assembly, disassembly, transport, reprocessing, and reassembly
R17	Provide a means of handling components during disassembly – handling during disassembly may require points of connection for lifting equipment or temporary supporting devices
R18	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
R19	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
R20	Design joints and connectors to withstand repeated use – minimise damage and wear and tear from the assembly/disassembly procedure
R21	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
R22	Make the most reusable parts most accessible – to allow maximum advantage from a reuse program
R23	Provide permanent identification of component type – similar to material identification, may use electronically readable information

	such as barcodes to international standards

Table 4 Design for deconstruction guidelines for building adaptability or relocation

No.	***Guideline***
B24	Standardise the parts while allowing for an infinite variety of the building as a whole – this will allow minor alterations to the building without major building works
B25	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
B26	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
B27	Use lightweight materials and components – this will make handling easier, quicker, and less costly, thereby making reuse a more attractive option
B28	Permanently identify point of disassembly – points of disassembly should be clearly identifiable and not be confused with other design features
B29	Provide spare parts and on site storage for them (especially for custom built components) – both to replace damaged components and to facilitate minor alterations to the building
B30	Sustain all information on the building manufacture and assembly process – measures should be taken to ensure the preservation of information such as ‘as built drawing’, information about disassembly process, material and component life expectancy, and maintenance requirements

ASSESSMENT MATRIX

These guidelines can be used by an architect or designer to assess a building design or existing building for deconstructability. They can also be used in the design process from inception to assist in designing new buildings for future deconstruction.

Qualitative Assessment

In the process of assessment, the building might be assessed in respect to each of the four levels of reuse, from recycling to total building relocation or adaptability. This would involve assessing compliance of the building firstly with those guidelines that affect the whole building, then working down in scale to material considerations. A matrix could be used to tabulate each component or system of the building. Figure 2 illustrates a matrix for an operable window system in a building using ‘standard’ construction technology. A qualitative assessment of this nature can be used to highlight the probable end of life scenario for building elements and materials. It will also bring to light those design features that could be altered to improve guideline compliance and thereby hopefully improve the rates of future reuse.

ITEM	*Fixing*		*Relevant guidelines*		*End of Life Option (most likely option highlighted)*	*Environmental relevance*	*Explanation of most likely end of life option and guideline compliance*
	Method	*Connected to*	*Complied with*	*Not complied with*			
Operable windows to upper floors	Fixed to frame by steel hinges, screw fixed to hinges	Cladding system of aluminium mullions and transoms	C8 C10 R13 R14 R16 B25	C7 C9 R15 R20 B26	Disposal - landfill Recycle Reprocess Reuse - as whole window sash	Relatively low quantity of window sashes	There are problems of external access required for removal. Small number of non-standard size windows reduces suitability for new building work.
MATERIALS							
Glass in operable windows	Held in place by pressure and structure of surrounding aluminium sash frame	Rigid silicone gasket	M2 M3 M6	M4	Disposal - landfill Recycle - return to glass smelter Reprocess - cut down to smaller sized pieces Reuse - as whole window sash with existing frame	Glass is inert as waste, but mechanically hazardous	Material is recyclable, but is most likely to be disposed as waste due to difficulty and danger in separating glass from rigid/fixed aluminium frame. Demolition results in small glass pieces in mixed rubble, too difficult and dangerous to separate.
Rigid Silicone gasket	Held in place by pressure and structure of the surrounding aluminium sash frame	Glass and aluminium sash frame		M3 M4 M6	Disposal – landfill Recycle – problems of plastic type identification and non-recyclability of some plastic types Reprocessing – cut to shorter lengths for use as gasket in smaller windows Reuse - as whole window sash with existing glass and frame	Petro-chemical material is toxic and hazardous in production and disposal	Most likely to be disposed as waste. Problems of identifying type of plastic. Thermosetting petro-chemicals can not be recycled, may however be possible to down cycle to alternative product bit there is to difficulty of separation after demolition due to contamination of material (gets dirty easily).
Aluminium sash frame to operable windows	Fixed only to silicone gasket – and screw fixed to hinges and frame	Rigid silicone gasket, and steel hinges	M1 M3 M5	M4	Disposal – landfill Recycle – to aluminium smelter Reprocess – cut down extrusions for use in smaller windows Reuse - as whole window sash with existing frame	Production of the aluminium frame is a high energy and pollution process	Reasonably possible to be separated for recycling to aluminium smelter, due to high cost of aluminium, ease of separation or sorting after demolition, and existing recycling infrastructure (possible problems of mechanically connected steel hinges).
Steel hinges	Screw fixed	Fixed to sash and fixed aluminium frames	M3	M2 M4 M5	Disposal – landfill Recycle – to steel smelter Reprocess - nil Reuse - as whole window sash with existing frame	Steel production is a high energy and pollution process – low quantities of hinges	If windows are demolished hinges will be damages or later damaged in removal/sorting from aluminium. Low cost of material makes sorting for recycling too expensive.

Figure 2 Design for deconstruction assessment matrix (example for 'standard' construction)

Quantitative Assessment

While this matrix provides for only qualitative assessment it would be possible to add an extra level of assessment to the process. It would be possible to add either a quantitative environmental assessment or a financial assessment to determine the specific environmental or financial benefits and costs of various options.

As already discussed, there are certain limitations of quantitative environmental assessment. It may however be possible to include a design for deconstruction assessment in a more general life cycle assessment if sufficient accurate date is available to make a reliable judgement. There are numerous life cycle assessment tools, many of which make quantitative assessments [12]. The design for deconstruction matrix could be incorporated into such a tool to provide a more detailed quantitative assessment of the end or life stage of the building. The matrix could be used to identify the most probable end of life option for each material and component, then an assessment can be made of the impacts of that option.

CONCLUSIONS

If the enormous loss of materials and energy that currently typifies the construction industry is to be addressed, one of the long-term strategies to be investigated is design for future deconstruction. One of the greatest barriers to component and material reuse is the difficulty of disassembly. The guidelines being developed here can be used as a starting point to design better buildings and improve the potential for deconstruction.

Certain building types will lend themselves more to deconstruction for component reuse than others, and some will be more suited to materials recycling. These guidelines should be used with other issues in mind to help achieve a certain improvement in building reuse, and within a holistic view of better building for reduced environmental burden. This strategy of design for deconstruction represents a long-term investment in the improved future of the built environment.

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