UNDERSTANDING THE CONCEPT OF FLEXIBILITY IN DESIGN FOR DECONSTRUCTION

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ABSTRACT

Design for deconstruction (DFD) means the design of a building and its components with intent to manage its end-of-life more efficiently. Adopting DFD principles during the design stage of a construction project can ensure building flexibility for adaptive use and easy component and material disassembly for reuse and recycling. Incorporating DFD principles at building design stage will ensure that both the asset management and building removal processes are conducted more efficiently with minimum resource consumption and environmental impact. Building flexibility can also be enhanced through the selection of a suitable design team that is committed to environmentally responsible construction, incorporating flexibility principles and the use of innovative construction methods. A new perspective that is increasingly being debated is that of considering existing buildings as a resource pool for future building material needs. In order for buildings to fulfil this role DFD will be a key factor in the retrievability of components and materials for extended use in future projects. This paper will describe the issues that need to be considered during DFD in order to ensure building flexibility.

KEYWORDS: Durability, Adaptability, Flexibility, Design for Deconstruction

INTRODUCTION

Design for deconstruction (DFD) refers to the design of a building with the intent to manage its end-of-life more efficiently. It ensures the easy disassembly of buildings in order to reduce waste generation and maximise the recovery of high value secondary building components and materials for reuse and recycling. This process encourages designers to incorporate flexibility into buildings at the design stage in order to ensure efficient building operation, maintenance and removal. By allowing for a variety of scenarios for building management from its occupation to its decommissioning, DFD reinforces the need and advantage of considering the whole life cycle of a building and its components.

One key determinant of successful building disassembly is the ability and ease of component and material recovery. Much of the current difficulties with building deconstruction are a result of the inflexibility of existing buildings, which were not designed to be taken apart. Existing buildings are increasingly being seen as one of the preferred resource pools for material extraction to satisfy future construction needs. For buildings to fulfil this role successfully, component and material retrievability will be very important, which in turn depends on the design approach employed at the beginning.

This paper will explain the concept of flexibility and show how and where it must be incorporated in design for deconstruction to yield buildings that are fit enough to last and versatile enough to accommodate changes in the environment. Section 2 defines flexibility, sections 3-6 look at construction process considerations, section 7 presents a list of principles for design for flexibility and section 8 gives a hierarchy of end-of-life options for buildings and their components.

WHAT IS FLEXIBILITY?

Buildings are constructed to last and satisfy the needs of the user. In technical terms, they are expected to have longevity. The longevity of a building is determined by the building's ability to maintain structural integrity for a long time as well as maintain desirability in terms of its functionality and style [1]. Structural integrity is determined by the quality of construction (i.e. material strength and construction method) and the durability of materials. Desirability on the other hand is determined by the building's ability to adjust to the demands of a changing environment, termed adaptability.

Durability is a quality incorporated in the design of buildings to ensure that a building is able to withstand various conditions that it will be exposed to over time. Designing for durability can save costs and reduce the negative impacts related to building operation and maintenance e.g. the consumption of materials during renovations and the resultant waste generation. However, if a building becomes obsolete long before its intended structural end-of-life, the above can be reversed i.e. the incurred costs of durable materials (usually expensive) may not be recovered because of the building's short life [2].

Adaptability allows a building to be versatile enough to accommodate the changing requirements of the physical environment within which it exists and the users which occupy it [1]. Changes may affect the exterior and/or interior of a building. The building needs to be designed in such a manner as to allow for modifications of either of these without affecting the other.

A strike of balance between durability and adaptability in the design of a building is thus very important. This balance is called flexibility – an important quality in buildings that are designed and constructed according to the principles of sustainable construction.

Taking the concept of flexibility beyond technical bounds, one comes across the notion of process flexibility. Process flexibility focuses on the design and construction team and what influence they have on the building's final flexibility [3]. It has two areas i.e. flexibility in the decision making process of a project and the flexibility of the construction process (from idea generation to building decommissioning).

Designers are called upon to be flexible enough to identify and engage other stakeholders in the construction project. Where necessary, designers should take time to build capacity in green construction and find best practice examples of similar projects. User needs and changing trends in the surrounding environment should be incorporated in the design. Furthermore, the design team and contractors should be open to changes (where warranted) during the construction phase if this will lead to increased building flexibility.

STARTING POINT – SELECTING THE CLIENT TEAM

Decisions made during design affect the flexibility of buildings. Design also determines the retrievability of building components and materials in buildings. As indicated earlier, many of the current shortcomings of building deconstruction are because existing buildings were not designed to be disassembled. It can thus be stated that “design is at the heart of green construction”.

The client team as a whole plays a pivotal role in the direction taken by a construction project. The client (or owner) is said to be the main driver for waste prevention and green buildings [2]. This is because the client can specify what he/she is prepared to pay for and since he/she is likely to be the end user of the building, its performance is very important to him/her. However, in some cases the client is either unaware or unable to use this ability. The architect and engineer have a responsibility to look after the client’s interest, particularly if the client has limited knowledge. If designers are also unaware or lack experience in green building, then it is likely that the resulting building will lack the necessary inherent flexibility to be both durable and adaptable.

It is thus important for clients to be exposed to environmental information that can increase their knowledge of sustainable construction (this is mainly a government and construction industry responsibility). Through the implementation of programmes such as a contractor rating system and registers of green designers, clients can select a construction team that is committed to green buildings. Green designers are characterised by open-mindedness, consideration of the whole service life of buildings and concern for the environmental and social implications of construction activities (over and above the economic). Although such designers are not in abundance, more and more best practice examples are beginning to surface internationally.

Designers can contribute to achieving building flexibility by:

- Consciously incorporating principles that allow for building disassembly, and component and material reuse and recycling
- Incorporating secondary material use in new buildings
- Innovations in building conversions

It must however be acknowledged that some constraining factors need to be addressed if designers are to transform to a “Green Status”. These factors include:

- Fear of change (dependence on the norm, insecurities and misconceptions)
- Motivation (regulatory and financial incentives)
- Integrity (acceptance and certification of secondary materials)
- True vs. hidden costs (life cycle costing and environmental accounting)

- Recognition (rewarding resource efficiency not payment according to quantity or project cost)

BUILDING DESIGN

Designers are increasingly called upon to produce designs that take the entire building life cycle into consideration. Such designs are intended to accommodate issues such as the current trend of short functional tenure of specific user services in buildings with a long technical service life. Building obsolescence, whatever the cause, is becoming a major cost in the built environment e.g. capital costs of new developments replacing existing obsolete buildings, loss of value and energy embodied in obsolete buildings and costs associated with building removal, waste disposal and the associated environmental impacts.

Buildings have evolved from the age-old approach of being designed as “eternal entities” to the current notion of “finite contemporary buildings” designed to last anything from one decade to over a hundred years. The major shortcoming of the eternal building approach is the inherent inflexibility that makes building modification to suit a changing environment a cumbersome exercise. Craven *et al* point out that buildings with such inflexibility tend to generate more waste when modified and sometimes leave no other option but to be demolished [4]. Finite contemporary buildings on the other hand present a variety of design options that can be tailored to a specific user’s needs. Let us look at some of the building systems that are currently used.

Open buildings (Permanent core)

Permanent core buildings are designed according to the theory of buildings layers. This is an old approach to building design that has found renewed interest in support of building disassembly to extend the functional lifespan of buildings and simplify the building modification process. In his description of the theory of layers, Crowther argues that a building is incorrectly referred to in singular i.e. “a building” because of a misconception resulting from the reading of a building in a limited timeframe [5]. He goes on to say that no single building remains in its initial “whole” state of construction for more than a few years or a couple of decades. The building is continually changed by activities such as remodelling, repair, expansions and maintenance. These activities alter the building’s exterior, interior or both.

If buildings are designed in cognisance of their layered nature to begin with, subsequent modification (i.e. removing and replacing components and adding extensions) can be much easier. To this end, it is recommended that buildings be viewed to consist of the following layers [5]:

- Structure – foundation and load bearing components
- Skin – cladding and roofing system
- Services – electrical, hydraulic, HVAC etc
- Space plan – interior e.g. partitions, finishes and furniture

Modular Buildings

There are different types of modular buildings that are available in the market today. Modular construction is characterised by the industrial mass production of standardised modular building components. Modularised buildings are intended to form part of a new era of flexible construction systems that allow for user specific building configuration, having the advantage of being assembled on or off site as the need may be. Let us look at three examples of such systems.

Portable buildings

Portable buildings are designed and manufactured industrially. They are made of prefabricated modular building components that are configured according to building designs to cater for specific user needs. They are assembled in factories and transported to site. Factory assembly enables quick and flexible building configuration. It also eliminates long periods on site. The modular nature of building components enables easy component disassembly for replacement during maintenance. If no longer needed, the building can be relocated as a whole to another site.

On-site assembly buildings

These buildings are also designed and manufactured industrially. Building components are modularised and prefabricated. They are configured according to building design to suit user specific requirements. Components are assembled on site. The prefabricated system reduces the amount of time spent on site. Due to their modular nature, such buildings enable easy component disassembly for replacement and expansion purposes.

Demountable buildings

Demountable buildings are industrially manufactured modular buildings that are designed to adapt to changing use patterns [6]. They are particularly suitable for short service life building requirements. The building components are assembled on site. At the end of service life, the buildings are disassembled completely and stored for reassembly when needed (or transported to another site for immediate reassembly).

Modular buildings generally increase the flexibility of buildings by standardising processes and materials, and allowing for large-scale mass production and easy on site assembly. It must however be pointed out that there are shortcomings to this building technique as well. For instance in countries where the construction industry has a high dependency on labour, there may be problems with the industrialisation of the construction process as concerns may be highlighted of its threat to labour job security. Also, because this process will either require factory or on site building assembly the type of required labour will be specialised, thus threatening the low-skill to unskilled labour category. In addition, the standardisation of components (although not as unattractive as standardised buildings) may run a risk of not being acceptable to clients who generally want uniqueness in buildings. Other considerations include the project cost implications of industrialised buildings in terms of transportation, quality control, buildability and the possible use of composite materials.

CONSIDERATIONS FOR DESIGN FOR DECONSTRUCTION

Craven *et al* support the industrial manufacture of buildings. They make an interesting analogy of domestic products and how increasing pressure on the environmental impacts of product manufacture has resulted in tremendous innovation in this field. It is suggested that some of these technologies can be adopted for application in construction [4]. A good example of this is the concept of design for disassembly in product manufacture, which has been incorporated in design for deconstruction. However, Craven *et al* correctly point out that there is a big difference between the worlds of "construction" and "product manufacture" e.g. until recently, buildings were designed to last for long periods (sometimes over 100 years) when products generally have short lives (anything from a few months to 20 years). In addition, while appliances can easily be mass reproduced to be identical, buildings are site specific with different and, at times, unique configurations.

Lessons learned from other sectors can help improve building construction practice if carefully assessed and adapted to the conditions of the construction industry. For instance contemporary industrialised buildings that have lifespans of 15-20 years (similar to many consumer products) need to be designed for flexibility to allow for modification and component (or material) recovery. In case where different components have different lifespans, the recovery of one material should not affect the entire structure. This can also incorporate initiatives such as product branding.

Design for disassembly and modular construction encourage and promote the standardisation of component manufacture, construction methods, component fixing etc. but consciously stop short of encouraging standard buildings[1]. While it is recommended that building methods and processes be standardised to improve efficiency and allow for material life extension, the uniqueness of individual buildings remains an important performance quality of the built environment.

MATERIAL CONSIDERATIONS

When designing buildings for deconstruction, care should be taken in the selection of building materials. The material selection process must be guided by the principles of sustainable construction and design for deconstruction. Table 1 gives a summary of some of the issues that have to be considered.

Table 1: Building component considerations for design for deconstruction, source [1]

Component	Elements	Materials	Comment
Foundation and floor	Foundation Floor bed	Concrete Timber	Concrete – cannot be reused immediately, but can be recycled into secondary materials

[1] Standard buildings are often not socially acceptable and are perceived to be of a low quality [4].

	Floor finish	Ceramics Carpets	Timber – can be reused immediately and recycled into various products Ceramics – durable, cannot be reused immediately, but can be recycled Carpets – recyclable, but process complicated, small market
Walls	Frame Siding Wall finish	Timber Steel Concrete Brick Gypsum drywall	Timber *as above* Steel – needs extra care if immediate reuse is considered, most recycled material Concrete *as above* Brick – high reuse potential, can be recycled into secondary materials Gypsum drywall – highest percentage of generated construction waste, recyclable if not contaminated, small market
Roof	Frame Sheeting Ceiling	Timber Metal Asphalt Concrete Polymers Gypsum	Timber – *as above* Metal – durable, costly initially but cheaper in long term, most recycled category of materials, established secondary market Asphalt – affordable, not reusable initially, can be recycled to road materials depending on prevailing policy Concrete *as above* Polymers – usually composite, not reusable or recyclable Gypsum *as above*

Note: All of the above components will generally be insulated. Insulation material is not directly reusable but depending on the type of insulating material, can be recycled. The market is however relatively small.

PRINCIPLES FOR ACHIEVING FLEXIBILITY IN BUILDINGS

The cornerstone of understanding flexibility in buildings is realising and acknowledging that:

- Buildings cannot live forever
- Buildings consist of layers that serve different purposes and have different service lifespans
- Building performance over time is directly related to user and environment requirements

The following principles can be used to ensure building flexibility during design for deconstruction [3][2].

[2] All principles adopted from [3] except for principles 1 and 2 as shown.

1. Be guided by the principles of sustainable construction [7]

- Minimise resource consumption
- Maximise resource reuse
- Use renewable resources
- Protect the natural environment
- Create a healthy, non toxic environment
- Pursue quality in creating a built environment

2. Use the principles of design for deconstruction [1]

- Information – Keep records of all construction documents
- Design – Balance durability and adaptability
- Materials – Use a minimum, reuse, conserve and avoid composites
- Connections – Use minimum, standardise and reuse
- Material salvage – Make decisions based on end use hierarchy options

3. Integrate the design of installation systems into the structural building design
4. Avoid running installations through structural sections
5. Separate the structural and infill elements of a building
6. Work from maximum partitioning of the building inward, not the reverse
7. Design the core structure to be partitionable
8. Give specifications for connections, structural and installations
9. Use modular coordinated systems
10. Make building components readily accessible
11. Localise services and control facilities, and provide central coordination
12. Provide capacity for future expansion
13. Restrict distribution facilities and ducts (where possible)
14. Use removable facilities instead of fixed installations
15. Ensure flexibility in the building and the process of building construction

END USE SCENARIO HIERARCHY OF OPTIONS

There is now general consensus on the destiny of a building, its components and materials at the end-of-life. Depending on a variety of prevailing conditions, the possible applications include those given in Figure 1.

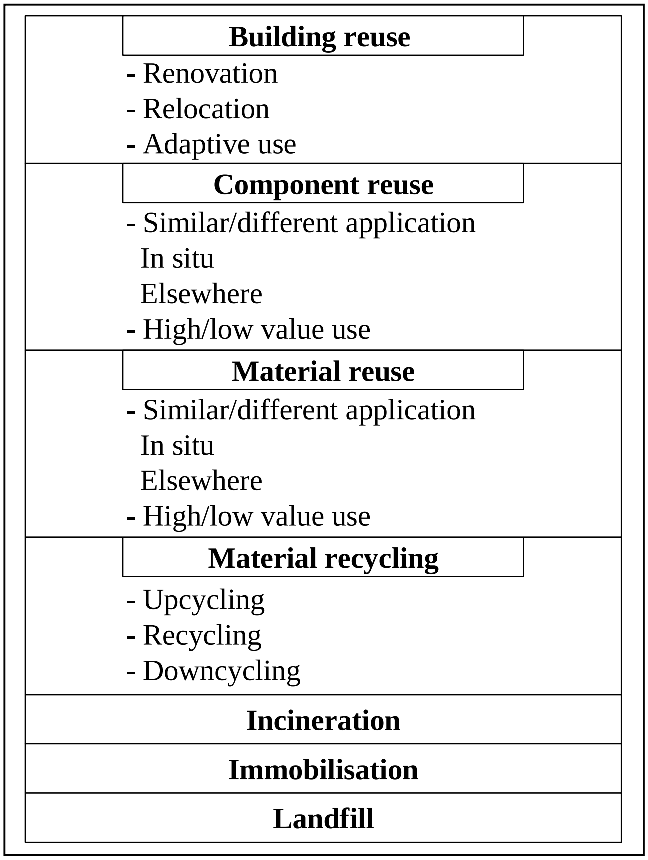

Figure 1: Hierarchy of possible end use options

Figure 1 is particularly useful if used during the design stage of the building construction process. If used in conjunction with design for deconstruction, the hierarchy of end-of-life options will help determine the implications of the decisions that are made at design stage e.g. selection of building design, construction method, materials, connections, fixtures etc. and their implications in terms of recovery, reusability, recyclability and so on.

CONCLUSIONS

- To ensure building flexibility, a balance must be struck between adaptability and durability.
- Flexibility in construction does not only mean the building's technical flexibility, it also extends to the construction process.
- Design is at the heart of green construction and selecting a good design team will improve the chances of yielding a flexible building.
- Design systems, construction methods and building materials if carefully selected, guided by the principles of flexibility, sustainable construction and design for deconstruction, will yield flexible buildings.
- Producing designs for carrying out building disassembly at the building design stage will improve the chances of success of building deconstruction.

REFERENCES

1. **Macozoma D S**, *Building Deconstruction*, CSIR Building and Construction Technology, South Africa, CIB publication, December 2001.

2. **Fishbein Bette K**, *Building for the Future: Strategies to Reduce Construction and Demolition Waste in Municipal Projects,* INFORM, June 1998.

3. **Geraedts Rob P**, *Upgrading the Flexibility of Buildings*, Delft University, Netherlands, in proceedings of the CIB World Building Congress, Wellington, New Zealand, April 2001.

4. **Craven DJ, Okraglik HM and Eilenberg IM**, *Construction Waste and a New Design Methodology,* proceedings of the First International Conference on Sustainable Construction, CIB Task Group 16, Tampa, Florida, USA, November 1994.

5. **Crowther P**, *Developing an Inclusive Model for Design for Deconstruction,* Queensland University of Technology, Australia, in proceedings of the CIB Task Group 39 Meeting, Wellington, New Zealand, April 2001.

6. **Zeegers A, Hermans M and Ang G**, *In Search for Design Criteria for the Delivery of Industrialised, Flexible and Demountable Buildings, A Performance Based Model,* Netherlands, in proceedings of the CIB World Building Congress, Wellington, New Zealand, April 2001.

7. **Kibert Charles J**, *Establishing Principles and a Model for Sustainable Construction,* proceedings of the First International Conference on Sustainable Construction, CIB Task Group 16, Tampa, Florida, USA, November 1994.