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ENVIRONMENT DESIGN GUIDE

DESIGN FOR ADAPTABILITY — AN INTRODUCTION TO THE PRINCIPLES AND BASIC STRATEGIES

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SUMMARY OF

ACTIONS TOWARDS SUSTAINABLE OUTCOMES

Environmental Issues/Principal Impacts

- Increasing the adaptability of buildings.
- Keeping buildings and building materials in productive use longer.
- Reducing the life-cycle environmental impacts of resource consumption, building material production and demolition waste.

Basic Strategies

In many design situations, boundaries and constraints limit the application of cutting EDGe actions. In these circumstances, designers should at least consider the following:

- Start with the end in mind
- Plan for change
- Design for long-life
- Design for loose-fit
- Design for deconstruction

Cutting EDGe Strategies

- Treat the building as a dynamic system.
- Consider the end-of-life scenarios of the building as a whole and then the various layers and components comprising its construction and function.
- Identify temporal layers of the building and their life spans by analysing the brief and context for the building.
- Create healthy and valued human environments by integrating with bio-climatic and biophillic design principles.
- Consider how the building can improve its service and value over time including planning for building maintenance.
- Decide on the mix of deconstruction to apply to building layers, elements and materials.
- Keep project construction and deconstruction documentation available for the life of the project.

Synergies and References

- *BDP Environment Design Guide:* TEC 1, CAS 18, CAS 21, PRO 9
- CIB Task Group 39 – Deconstruction – http://www.cce.ufl.edu/affiliations/cib/index.html
- Brand, S. (1994), *How Buildings Learn: What Happens After They're Built,* Penguin Books, New York, U.S.A.
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This note introduces the concept of Design for Adaptability as an essential strategy for creating sustainable buildings. The approach requires life-cycle thinking and the ability to understand how buildings can be designed to be flexible and resilient to human and environmentally induced change. By designing for adaptability, designers acknowledge that sustainability is an emergent quality of a building, not a performance measure and that a building should be designed in ways that diminish the likelihood of it becoming obsolete.

1.0 INTRODUCTION

Imagine a building industry that uses environmentally benign or even beneficial manufacturing processes, which closes material loops so there is no waste, and relies on cities as the main source of raw material for building. Imagine buildings and industrial systems that mimic and integrate with natural processes and increase the health and resilience of ecosystems. Imagine a built environment containing buildings that help people feel well, that manage to inspire or to comfort, that are cheap to operate and easy to maintain, and that can be mined for materials and components to make new buildings. In such a world there would be lower consumption of raw materials from nature, lower consumption of energy, less environmental damage, slower climate change, no material waste and healthy people. If we had such a world we would want to sustain it.

With construction and demolition waste accounting for between 16-43 percent of the total solid waste stream (Graham, 2003), no eco-labelling scheme for building materials, and recycling rates of just over 50 per cent of materials from demolition (Tucker et al., 1996) we clearly have some way to go before the building industry and the built environment in Australia operate sustainably. We therefore face a design challenge to make best use of the buildings we already have, reduce our consumption of new resources for building, eliminate waste by closing material loops, and design buildings that allow easy access to materials for future reuse or recycling.

An important strategy for addressing this design challenge is *Design for Adaptability*, a framework for building design aimed at maximising the time that buildings, building components and materials remain in productive use. The building industry globally causes about 40 per cent of humanity's annual resource consumption and the many life-cycle environmental impacts of building materials (explained in detail in *BDP Environment Design Guide* notes TEC 1, PRO 1, PRO 2 and PRO 9) highlight the need for a holistic approach to building design that provides a framework for sustainable material use. *Design for Adaptability* provides a theory and set of principles for sustainable material use in the same way that *Bio-climatic Design* (e.g. Yeang, 1996) provides theory and principles for sustainable energy use. These design frameworks are interdependent and are essential for designing buildings that can sustain healthy environments, that can sustain their service and their value, and that can sustain our access to building materials.

This note is intended as an introduction to the basic theory and principles for designing for adaptability. It begins by defining *Design for Adaptability*, and explains the five principles applied to designing for adaptability. A number of buildings that have been designed for adaptability are then presented as examples of how these principles are practically applied.

2.0 WHAT IS DESIGN FOR ADAPTABILITY?

Design for Adaptability is primarily a strategy used to avoid building obsolescence, and the associated environmental and cost impacts of resource consumption and material waste. From a reading of building life cycle research the different ways buildings can become obsolete can be described in terms of:

- Service factors such as building components being damaged, worn, poorly designed, constructed or maintained, poor space-plan and ergonomic considerations, changing working environments, increased or decreased space requirements, shifts in the population or changes in the aspirations of the principle user group, poor internal environmental quality, changes in building codes and other regulations.
- Value factors such as reductions in the financial value of the building, increases in the cost of operation and maintenance, changes in perceptions of aesthetic quality and popular style, and the availability of more valuable alternatives.

While many of the service factors for obsolescence fall within the influence of building design, it is difficult to anticipate many of the value pressures at the design phase. Designers are therefore encouraged to design buildings that can either maintain their service and value or design buildings that can easily incorporate changes with minimal consumption of resources or production of waste throughout the building life span.

It is important to remember that a sustainable building is not one that must last forever, but one that can easily adapt to change. The ability for a building to be adapted in these ways can be described as a building's flexibility and must be considered in relation to the required durability of a building over its life span.

The theoretical underpinning of *Design for Adaptability* is abandoning the concept of a building as a static object and instead seeing it as a system of constructed layers with different life spans. The process of designing for adaptability therefore requires the designer to ask – should I try to achieve flexibility in the building as a whole? What is the correct balance between flexibility and durability? Should I be designing for adaptability of building function, structure, space, components, systems, services or something else? Answering these questions requires an investigation of the life span and use of a building, and careful analysis of the life span of the elements of buildings in order to determine which parts of a building will change, and when and how. Being aware of how buildings change over their life span allows designers to provide flexibility to short life-span building layers and durability to long life-span layers, and to organise layers so that fast-cycling materials can be changed without damaging slow-cycling materials. Maintenance planning is therefore also an essential for realising the environmental benefits of designing for adaptability.

We have come to know this type of design exercise as 'long-life, loose-fit' design, which came before the term 'ecological design'. This particular formulation of environmental design goals is useful in organising a contemporary approach to designing for adaptability because it provides a framework for making strategic decisions about the right mix of flexibility and durability in a building. If we add to these the need to design for deconstruction to address concerns for the fate of building materials beyond the life of the building, we have a set of principles for applying Design for Adaptability theory in the design process.

3.0 PRINCIPLES OF DESIGN FOR ADAPTABILITY

Based on a reading of theory for sustainable design a number of basic principles can be distilled as a foundation for *Design for Adaptability* strategies. These principles, described in detail below are:

- Start with the end in mind
- Plan for change
- Design for long-life
- Design for loose-fit
- Design for deconstruction.

3.1 Start with the end in mind

Basic strategy

- Begin by considering the end-of-life scenarios of the building as a whole and then the various layers and components comprising its construction and function.

Designing a building with its end in mind is important because it helps clarify where and when the qualities of durability and flexibility are required. Are we for example likely to be:

- Re-using the building for the same use? In which case a large degree of functional and physical resilience is required.
- Re-using the building for a different use? In which case a balance of structural durability and space-plan flexibility is required.
- Re-using elements of the building? In which case these elements must be durable and provided with flexible connections to assist in deconstruction.
- Re-using building materials? In which case it is important to use fixing techniques that allow for dismantling without damaging the materials.

3.2 Plan for change

Basic strategies

- Treat the building as a dynamic system
- Identify temporal layers of the building and their life spans by analysing the brief and context for the building.

A building is a dynamic system

> *'…there isn't such a thing as a building…a building properly conceived is several layers of longevity of built components'* (Duffy, 1990).

Design for Adaptability is based on two principal theoretical propositions. The first is that a building is not a static object, but both the object and process of construction and reconstruction. The second proposition is that 'the building' can be thought of as a system of constructed layers defined by their life span.

We tend to think of a building as a discrete whole object. We design a building, which is located on a site as a 'closed' system in which the walls and roof define the inside and the outside. It is predominantly designed to look and operate at its best as soon as it has been constructed. The passage of time is assumed to bring with it decay. From the perspective of *Design for Adaptability* (and more broadly from the perspective of ecological design) this view is inaccurate.

The basic theoretical position taken in *Design for Adaptability* is that buildings are not static objects, but dynamic systems constructed of layers with different life spans and life cycles. Beyond a building's walls are material supply chains and natural systems, which are both the source and sink for resources and waste. These chains of interdependency exist for the life span of the building with the existent structure read both as a record of past relationships, and as an indicator of future opportunities. In order to design for adaptability equivalent consideration is given to the verb 'building' as is given to the noun. Designing for adaptability therefore requires consideration of the interplay between time, change and longevity as generators of form.

Considering these factors as generators of form raises the question of what aspects of a building will change and what aspects will endure. Vernacular traditions such as those of the Japanese, design for endurance in the structure and flexibility in space-plan. Their vernacular building achieves this by separating the structural frame from the spatial frame allowing deconstruction and reconstruction in response to the changing needs of the occupants without damaging structure or wasting materials (Crowther, 2001). As Habraken (1972) observed:

> *'Japanese wooden architecture … is a complete architectural system in which the expansion, remodelling, removal and reconstruction of buildings is possible according to lifestyles'* (cited in Crowther, 2001).

This vernacular response to change by perceiving a building as layers with different life spans has been developed through the work of designers such as John Habraken's *Support Structures* (Crowther, 2001), (a contemporary expression of which can be seen in the social housing system designs for Chongqing by Battle and McCarthy, 2003), Archigram in the UK and the Japanese Metabolists. Each of these movements were concerned with providing the ability to change components of a building or built environment without having to disturb the entire building by separating buildings into time-related (temporal) layers (Crowther, 2001).

A building has 'temporal layers'

Considering a building as temporal layers of system and structure allows building design to be ordered around groupings of elements with similar life expectancy. Considering the life span of the layers of a building is a simple exercise in life cycle thinking, which requires the designer to think about construction, maintenance, deconstruction, and the fate of building components and materials beyond the life of the building.

Many practitioners and researchers have segregated building into temporal layers. Some such as Archigram and Kurokawa have looked at temporal layers of building on an urban scale, proposing standard life spans for different building types and urban features including, in the case of Kurokawa (1977), natural areas. Others such as Duffy (1990) and Brand (1994) focus on the layers of a building and propose life spans for each layer. Comparative studies by Crowther (2001) indicate that there is little consistency in the predicted life spans of different building layers beyond the general observation that for most buildings the structure should be the most enduring building layer followed by the building envelope, then services and space-plan. Brand, Duffy and Kurokawa also consider the life span of consumer goods that are brought into the building as necessary considerations to adaptable design.

Brand's model of 'shearing layers of change' has been widely cited in recent years by researchers concerned with the development of design theory in the areas of ecological design and construction ecology (e.g. Kibert et al., 2002; Graham, 2003) and also in relation to principles of design for deconstruction (e.g. Crowther, 2001; Guy and Shell, 2001 and Graham, 2002). We will therefore adopt Brand's descriptions of temporal layers in order to allow our theory for *Design for Adaptability* to be generalised. Brand's 'shearing layers of change' in buildings are described in Table 1.

3.3 Design for long-life

Basic Strategies

- Design the structure so that it is strong enough to cater to different building uses and loading scenarios
- Dimension structural frames to assist the adaptation of the space-plan to different types of building use
- Establish a structural grid that permits modular skin and space plan design
- Provide durable amenity by integrating with bio-climatic and biophilic design principles
- Consider how the building can improve its service and value over time.

Durable Structure

Referring to our temporal building layers we can infer that we should be designing for durable structures, and depending on the building type, long-life building skin. In the context of adaptability, we also need to design buildings that provide durable amenity. And because we are interested in closing material loops, a consideration of long-life is not complete without developing a clear idea of what the end-of-life scenarios for the building are. Fundamental to designing for adaptability is designing the building's structure to be strong enough to cater to different building uses and loading scenarios over time, and dimensioning the structural frame to allow for the adaptation of the space-plan to different

Table 1. Generic temporal layers of a building (based on Brand, 1994)

Layer	Description	Life-span
Site	Physical setting for the building	Eternal
Structure	Foundations and load-bearing system	30-300 years
Skin	Cladding, walls, roofs, protection and control of climate and environmental conditions	20 years
Services	Energy, HVAC, data, hydraulic, lifts, lights, fire, etc	7-15 years
Space-plan	Internal partitions, ceilings, finishes, built-in furniture	3 years (commercial) > 30 years (domestic)
Stuff	Furniture, consumer goods, food, waste	Daily-monthly

categories of building use. A common strategy is using a structural grid that allows a modular building skin and space plan based on standard material dimensions.

There are many implications involved when changing the use of a building, from negotiating zoning and heritage requirements to anticipating building code requirements for different building types. A simple example of these related considerations is the issue of minimum ceiling height. The minimum for residential use is 2400mm while for commercial uses it is closer to 3000mm. It is therefore possible to change the use of a building from commercial to residential (as was the case with the conversion of Caltex House, Kent Street, Sydney in 1998, but not always possible to change a building from residential to commercial (as is the case with the Inkerman Oasis apartments in St Kilda, Melbourne, which has a ceiling height limit of 2700mm).

Durable Amenity

We tend to preserve places we feel good in (psychologically, health-wise, comfort-wise), and places we feel good about (social, economic and cultural values). *Durable Amenity* therefore relates to creating a building that sustains its service qualities and its value with minimum requirement for alterations that require the addition of material and the generation of waste. Careful consideration needs to be given to patterns of building use and the integration of design measures that maintain comfortable and healthy indoor environments. Thus maintenance becomes a key input to longevity and sustainability, and sustainable design should minimise maintenance needs and reliance of future owners.

Following principles of passive bioclimatic design requires the appropriate location of structure, enclosure and interior in relation to available sunlight, and prevailing wind as well as daily and seasonal variations in temperature. The effective implementation of bio-climatic design strategies reduces the need for mechanical heating, cooling and ventilation thus simplifying the layers of the building. A building with fewer services is more easily adapted to new uses and requires less maintenance.

Another important aspect of maintaining a building's function and value is creating indoor environments that are healthy for people and that have qualities that are likely to cause happiness. Researchers and practitioners have begun to realise that sustaining the amenity of a building does not just require making internal environments that don't cause harm, but creating environments that make us feel good. Key strategies require addressing our psychological need to be connected with nature in our buildings, also known as

Table 2. Characteristics of biophilic buildings (Heerwagen and Hase, 2000)

Principle	Qualities
Prospect (ability to see into the distance)	Brightness in view Visual distance Ability to get to a distant point for a better view Horizon/sky imagery Strategic viewing locations View corridors
Refuge (sense of enclosure or shelter)	Canopy effects (lowered ceilings, screening) Variation in light levels (darker suggests refuge) Enclosing surfaces Penetrable barriers and surfaces for views out
Water (indoors or views)	Glimmering or reflective surfaces (suggest clean water) Moving water Symbolic forms of water
Biodiversity	Varied vegetation indoors and out Windows designed and placed to incorporate nature views Outdoor vegetation areas with rich vegetation and animals
Sensory Variability	Changes in environmental colour, temperature, air movement, texture and light over time and space
Biomimicry	Design derived from nature Use of natural patterns, forms and textures Fractal characteristics
Playfulness	Incorporation of décor, artefacts, objects and spaces whose primary purpose is delight, surprise and amusement
Enticement	Discovered complexity Information richness that encourages exploration Curvilinear surfaces that gradually open up information

our *'biophilic'* needs (Wilson, 1984) and appropriately addressing ergonomics and security.

Human beings need to feel they are in 'the right place' in order to feel well. This is essentially a process of habitat selection. Holistic approaches to design of 'habitats for people' have been given many labels. The field has recently been given the label 'Human-centred Sustainable Design' by the US Green Building Council. Characteristics of a 'biophilic' building are presented in Table 2. Melbourne's Council House 2 (CH_2) Project and Campus NAB, and Sydney's UNSW Police HQ in Parramatta incorporate human-habitat responses in their designs.

3.4 Design for loose-fit

Basic strategies

- Decide on the building's required mix of spatial flexibility, structural flexibility or flexibility to assist building elements and material change
- Map or organise building layers according to their expected life span
- Develop a hierarchical strategy for connection detailing between layers based on replacement rate
- Use mechanical connections between layers of a building so that fast-cycling materials can be replaced without damaging or destroying slow cycling layers.

Loose fit is the aspect of *Design for Adaptability* that provides a framework for designing for flexibility. Decisions need to be made about whether the building needs spatial flexibility, structural flexibility or flexibility to assist building elements and material change. These key considerations have been described as:

- *Spatial transformations* – to ensure continuity in the usefulness of space
- *Structural transformations* – to provide continuity in the exploitation of building layers and components through replaceability, recovery and reuse
- *Element and material transformations* – to provide continuity of access to building materials for reuse and recycling.

(Durmisevic and Brouwer, 2001)

The type of transformations required in a particular building can be planned and construction systems and materials can be chosen to provide the required flexibility. The composition of building layers, and the way in which they are constructed and associated, determine the physical flexibility of a building. The characteristic of a building designed on the premise of 'loose fit' is the relationship between the integrity of the individual layers of a building, the independent arrangement of elements of the building and the connection detailing between each layer. Figure 1, for example, shows the concept design for flexibility in a house. Building layers are mapped in relation to their expected life span, and a hierarchical strategy for connection detailing between layers.

Designing for loose fit requires flexible connections between layers of a building so that fast-cycling materials can be replaced without damaging or destroying slow cycling layers. This basic principle can apply to a building at any scale from the whole building level, through to the components that make up each of its layers. Following this approach cannot only increase the adaptability of the building, but increases the ease of deconstruction.

3.5 Design for deconstruction

Basic strategies

- Decide on the mix of deconstruction to apply to building layers, elements and materials
- Keep building elements with different functions independent of each other
- Determine both the construction and deconstruction sequence including lifting and transporting

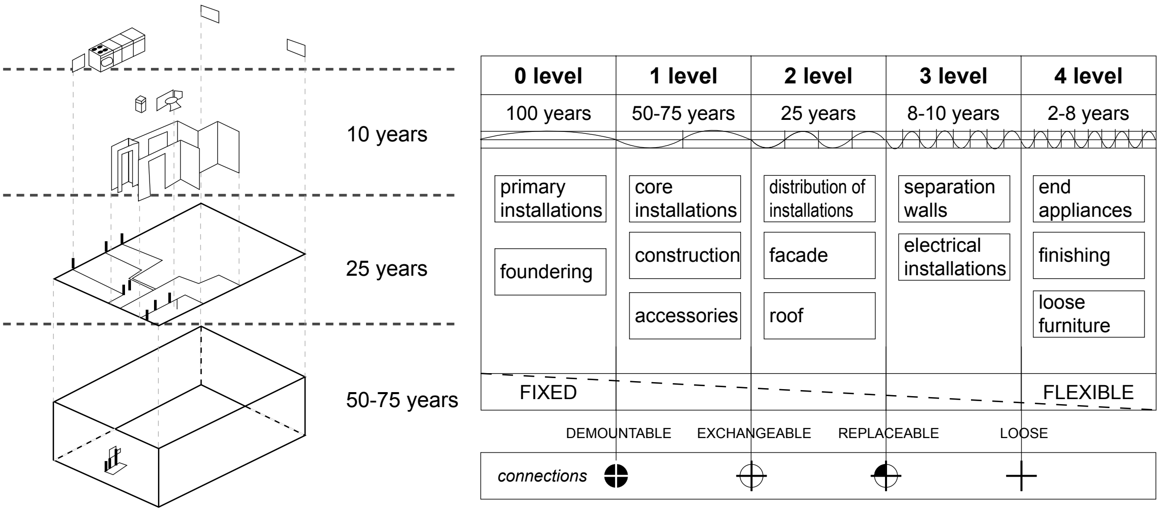

Figure 1. A 'Design for Adaptability' concept for a Dutch House (Durmisevic and Brouwer, 2002)

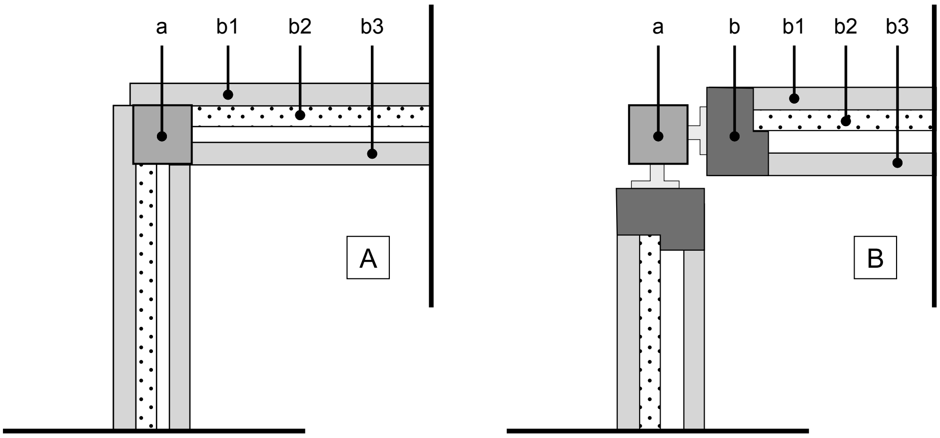

Figure 2. Wall section A is not designed for deconstruction. Wall section B is designed for deconstruction (Durmisevic and Brouwer, 2002)

- Use mechanical rather than chemical connections
- Keep project construction and deconstruction documentation available for the life of the project.

Design for deconstruction is dealt with specifically in *BDP Environment Design Guide* Note TEC 1 as a means for designing out waste by providing the potential for reusing building elements and materials at the end of their life. A building or building layer that is easily deconstructable is essentially an outcome of good long-life, loose-fit design. However, designing for deconstruction requires that specific attention be paid to the relationships and connections between building layers and components to ensure that there is an appropriate level of independence between their functions. In addition to long-life and loose fit considerations there are four important design rules for improving the ability to deconstruct a building or building element. They are:

- Try to keep building elements with different functions independent of each other. Avoid for example using a structural façade
- Use mechanical rather than chemical connections
- Consider the construction and deconstruction sequence. Locate large or heavy elements close to service shafts or the exterior of the building so that they can be easily lifted and transported
- Keep construction and deconstruction records available for the life of the building.

Figure 2 shows two alternative construction sections for a façade to illustrate the difference in detailing that the application of these rules makes. Assembly A is a fully integrated construction detail typically used in domestic construction. The structural element (a) is integral to the infill (b2) and the interior and exterior cladding. This configuration provides no opportunity to reuse wall elements. Assembly B shows clear separation of the structural element from the frame and the cladding and has introduced a mechanical connection detail to improve deconstructability.

Following these rules provides the best conditions for salvaging elements and materials for reuse or recycling. Intuitively assembly B looks to be a financially more expensive solution; however using modular dimensions that correspond to standard material sizes could reduce costs.

4.0 DESIGN FOR ADAPTABILITY – PRACTICE

The following examples have been chosen to show how simple design strategies can be integrated to improve the adaptability of buildings.

An example of the application can be seen in the Renzo Piano and Richard Rogers design of the B&B Italia Offices (Piano and Rogers, 1973) which was in the architect's words 'a test-bed for ideas that would be used to inform the Pompidou Centre'. Figures 3 and 4 show in elevation and section the integrity of each of the layers of the building and their loose-coupling with each other.

Figure 3. Italia offices – elevation (source: Buchanan, 1993)

The design for the Harbour House in Newcastle by Bourne & Blue + Stutchbury & Tate, winner of a UNSW Architecture Award in 2004 (Figures 5 and 6) provide a local example of *Design for Adaptability*.

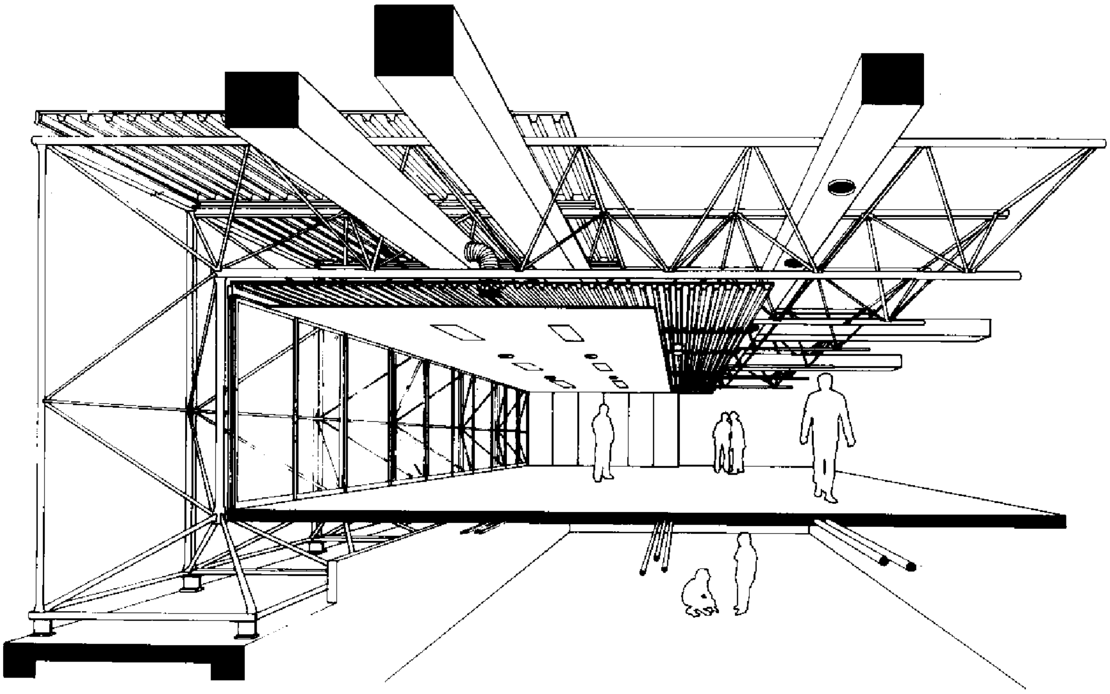

Figure 4. Italia offices – section (source: Buchanan, 1993)

Figure 5 shows bedrooms arranged in a gallery with the height of the walls and the spacing of columns relating to standard marine-ply sheet sizes. Large bedrooms are two modules wide on plan. Note also the light fittings do not penetrate ceilings.

Figure 6 shows how the use of bolted connections and appropriately strong materials (in this case recycled Australian hardwood) will assist deconstruction.

Figure 5. Interior gallery – Harbour House

Figure 6. Connection detail – Harbour House

Figure 7 shows the interior of the Ostratorn School in Lund, Sweden as a good example of adaptable design integrated with bio-climatic strategies.

Figure 7. The design of Ostratorn School, Lund, Sweden, effectively integrates material choice with bio-climatic design (Graham, 2003)

Notice that the structure and envelope are loosely coupled; that the interior space plan is created using lightweight non-load bearing partitions, and that the thermal mass material (concrete floor and recycled brickwork) is used inside the double-glazed envelope to retain heat in surfaces that people come into direct contact with. This takes advantage of the effectiveness of radiant heating and cooling and avoids the need for heating and cooling space. The Ostratorn School in Lund also considered the eventual deconstruction of the building and built-in a 'black-box' to keep project information safe for the life span of the building (Figure 8).

5.0 CONCLUSION

The process of building is among the major environmental impacts of humanity so redesigning buildings to ensure they don't burden natural systems is an important design challenge. The vision of buildings and a building industry working in harmony with natural systems is not impossible to realize. However, our buildings and building products are not currently designed or built to allow disassembly and reuse.
This note has presented *Design for Adaptability* as a framework for encouraging the sustainable use of materials. The principles of this approach to building design are derived from an understanding of buildings as dynamic structures consisting of layers with different life spans. Following the principles; start with the end in mind, plan for change, design for long-life, design for loose-fit and design for deconstruction, will help create buildings that require less material resources and which can also become the major source of building materials in the future. Linking principles for *Design for Adaptability* with human-centered sustainable design, including bio-climatic design, creates a holistic design approach that will help sustain the service and value of buildings.

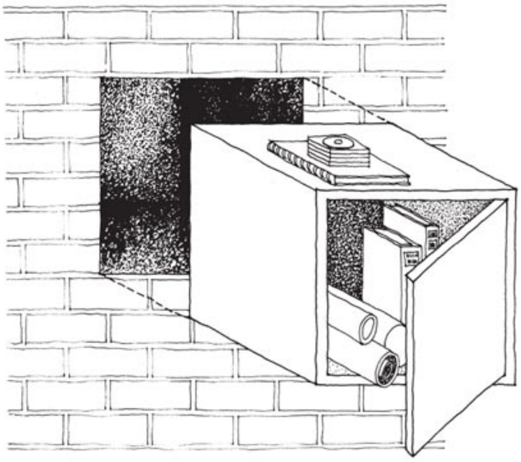

Figure 8. The school's 'Black Box', designed to keep project information safe for the life of the building so that it can be used in the future to assist deconstruction (Graham, 2003)

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Research

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The diagram and photograph in Figure 8 are reproduced here with the permission of White AB Architects, Lund Sweden.

BIOGRAPHY

Peter Graham (Mapp.Sci – Building, B.Build C.M., Grad. Cert TTL) is a lecturer and stream leader of Technologies in the Architecture Program at the University of New South Wales. Prior to this he was lecturer in Sustainable Construction at RMIT. Over the last six years he has developed undergraduate and post graduate environmental studies courses for building professionals in Australia and Singapore. He specializes in assessing the life-cycle sustainability of building. His international research includes work with the International Energy Agency, the International Council for Research and Innovation in Building Construction, and aid work in the Pacific. Peter works closely with the building industry in Australia, specializing in assisting the development of ESD briefs for public projects such as schools, hospitals and university buildings, and developing waste minimization programs for companies and industry bodies. Peter's first book *Building Ecology: First Principles for a sustainable built environment* has just been released by Blackwell Publishing.