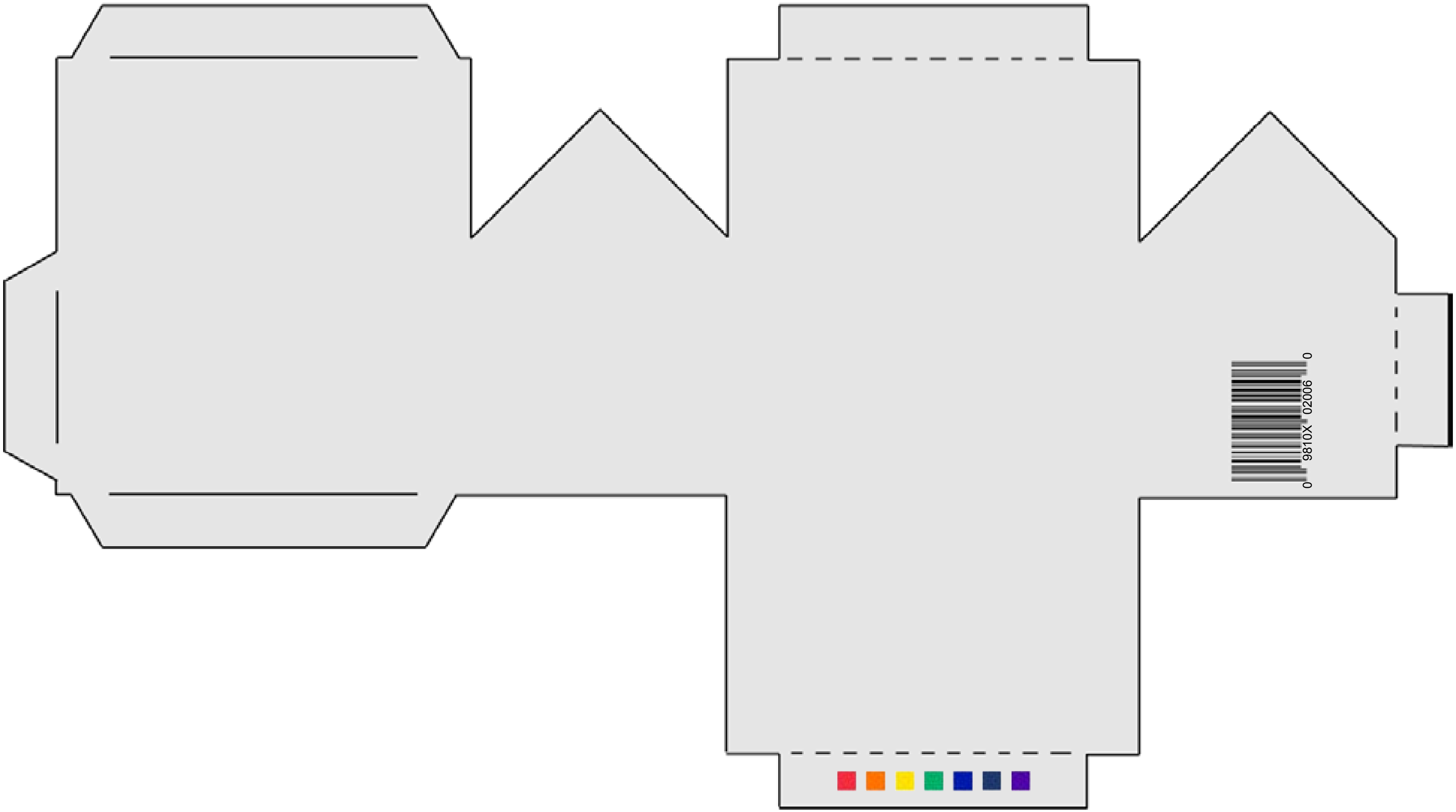
DfD

Design for Disassembly in the built environment:

a guide to closed-loop design and building



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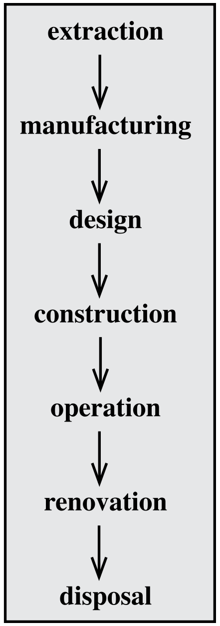
Introduction

DfD is a new concept for the design and building community and is an important contributor to Design for Environment (DfE). DfE is a comprehensive consideration of design related to environmental and human health impacts over the life-cycle of a product. There are many other sub-sets of DfE such as design for assembly, reuse and recycling but in fact DfD is integral to any design for... that intends to maximize materials conservation from building end-of-life management, and create adaptable buildings to avoid building removals altogether. Given that many buildings are removed from sites due to redevelopment and their inability to remain useful within an alternative land use, DfD can also be an intelligent strategy to prevent obselescense and mitigate economic factors (such as labor costs) that encourage destructive demolition and disposal of buildings.



typical building materials flow

Design for disassembly (DfD) is a growing topic within manufacturing industries as greater attention is devoted to the management of the end-of-life of products. This need is driven by the increasing disposal problems of large amounts of consumer goods, and the resultant pollutant impacts and loss of materials resources and energy that is embodied in these products. In Europe, in particular, constraints on the production of waste and pollution have resulted in an emphasis on "extended producer responsibility" legislation such as the Directive 2000/53/EC of the European Parliament on end-of-life vehicles and Germany's End-of-Life Vehicle Act of 2002. Extended producer responsibility (EPR) is defined as "…making the manufacturer of the product responsible for the entire life-cycle of the product and especially for the take-back, recycling and final disposal of the product" (Toffel, 2002). Simply put this requires that those who create a product are responsible for designing its entire life-cycle, including its ultimate disposition, with reuse and recycling, to achieve economic profitability at minimum risk. The elements of the 2000/53/EC related to EPR design and manufacturing processes include:

Fig. 1 BMW assembly line

- Reduction and control of hazardous materials.
- Requirements that dismantling reuse and recycling of vehicles and components is integrated into design and production.
- A certificate of destruction accounting for the recovery of the vehicle.
- Use of component and materials coding standards.
- Creation and dissemination of dismantling information for the correct and environmentally sound end-of-life treatment.
- Measurable targets of the average amount of materials by weight per vehicle to be recovered.

(Directive 2000/53/EC of the European Parliament, 2006)

As buildings are manufactured artifacts typically comprised of a combination of pre-assembled components and on-site assembly of materials and components, design for disassembly can be applied to the built environment similarly to other assembled artifacts. One major distinction for most buildings is the dominance of “wet” assembly, which is systems constructed for, and at, a specific geographic site. Literal “wet” construction such as cast-in-place concrete does not readily lend itself to separation for reuse. Although not typically considered a “product”, buildings are nonetheless composed of materials, components, and connections, and are created through the collaboration of designers, engineers, trade-persons, and the manufacturers of the materials and components that are assembled to make the building. Residential and civic buildings can also have profound meaning, similarly to craft objects, embodying shelter and comfort, and as cultural symbols, respectively. Because of their importance in society and tremendous impact on resource utilization globally, any attempt to consider sustainability in the use of building-related resources must consider the management of all resource flows in the full life-cycle of buildings from extraction, to manufacturing, to design, to construction, to operation, to renovation, to eventual end-of-life.

Fig. 2 according to US HUD the average American home built in 1950 was 1,000 sq. ft. in 2000 it exceeded 2,000 sq. ft.

There are many practical reasons for incorporating DfD in the built environment. The US Geological Survey has estimated that 60% of all materials flow (excluding food and fuel) in the US economy is consumed by the construction industry (Wagner, 2002). The US EPA has estimated that 92% of all construction-related waste produced annually in the US is the result of renovations and demolitions, with only 8% produced from new construction, and that this waste is upwards of 30% of all waste produced in the US (Franklin Associates, 1998). Nelson has estimated that the total built space in this country will need to grow from 296 billion square feet in 2000, to 427 billion square feet in 2030. Of this growth, 82 billion square feet of building will be from replacement of existing building space and 131 billion will be from new construction totaling 213 billion square feet of new built space.

This means that 27% of existing buildings in the year 2000 will be replaced from 2000 to 2030 and that over 50% of buildings in the year 2030 will have been built since 2000 (Nelson, 2004). This huge mass of buildings that are to be replaced and newly constructed can either be large sources of waste in the next generation after 2030, or they can incorporate DfD to recover their materials from future repairs, renovations, and removals.

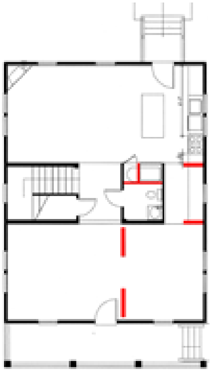


Fig. 3 existing plan

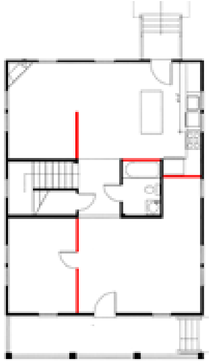


Fig. 4 future plan

Fig. 5 Community Housing Resource Center, Atlanta, GA: Design for Disassembly Case Study Home

DfD is intended to create buildings to reduce new materials consumption and waste in their construction, renovation and demolition, to increase building lives in situ, and to create buildings that are stocks of future building materials. This enabling of materials conservation and buildings that facilitate the recovery of their components for the next iteration is intended to provide both economic and environmental benefits for builders, owners and occupants, and the communities where these buildings reside.

Problems in Current Design

Generally buildings are difficult to adapt or deconstruct and recover the materials for reuse and recycling in a cost-effective manner. Some reasons include:

- Trends away from renewable and fiber-based materials to inorganic and organic minerals (petroleum) and the increased use of composites and engineered products which are difficult to recycle because of their chemical complexity.

- Costs of labor to deconstruct and process commingled recovered materials and the ability to use human, mechanical, thermal, optical and even sonic means of separation.

- Use of connection techniques such as pneumatically driven nails, staples and adhesives that are extremely difficult to "undo."

- Loss of craft skills such that the labor costs to create exposed connections and details that are also aesthetic, is prohibitive.

- Reliance on coatings and encapsulation of elements with innumerable layers of finish materials in lieu of integral envelope / finish / structural systems.

- The highly speculative nature of much building, whereby there is not a long-term ownership, and therefore adaptation, renovation and demolition costs are not borne by the original owner.

- The perception that incorporation of components and systems designed-to-be-disassembled, other than those explicitly meant to have short lives (exhibition spaces, entertainment venues, etc.) will reduce value and imply other aesthetic, or life / safety compromises.

According to the Building Materials Reuse Association, by a wide margin the most cited obstacle to deconstruction was "time to deconstruct" with "low disposal costs" second (Echols and Guy, 2004). While a designer may not be able to change disposal fees for construction and demolition waste, DfD can increase the efficiency of a disassembly process.

What is DfD ?

DfD is the design of buildings to facilitate future change and the eventual dismantlement (in part or whole) for recovery of systems, components and materials. This design process includes developing the assemblies, components, materials, construction techniques, and information and management systems to accomplish this goal. The recovery of materials is intended to maximize economic value and minimize environmental impacts through subsequent reuse, repair, remanufacture and recycling. Of last resort are energy recovery from materials and safe biodegradation. DfD enables flexibility, convertability, addition, and subtraction of whole-buildings. In this manner DfD may help avoid the removal of buildings altogether. DfD includes using reusable materials, materials intended as recycling feedstock, and "natural" materials that might be entirely biodegradable. It also seeks to ensure that all aspects of sustainable building are supported. In fact, there are many aspects of DfD such as reducing entangled electrical systems through utilizing day-lighting systems that also reduce energy-use and increase the health of the indoor environment. The end-result of an application such as day-lighting design will be a more dynamic building capable of adapting to multiple programs, technological updates and physical configurations over its lifetime.

Many vernacular and "primitive" structures were designed and built in symbiotic relationship with their surroundings where repair, mobility and change were needed. For example, DfD was integral to the Native American tipi or tepee which the plains tribes assembled and disassembled to accommodate their migratory patterns.

In traditional Japanese culture, the presence of timber, the mild climate, and earthquake-prone geography combined to create a craft-intensive architecture based on wood joinery that is highly dis-assembleable. The epitome of this tradition is found at the Ise Shrine where the inner sanctum has been dismantled and reconstructed every 20 years for the last 1,300 years. This process includes the stewardship of the timber resource used to build each new iteration and the reuse and dispersal of the dismantled shrine to other shrines across the country. Each dismantling and rebuilding cycle also maintains the traditional carpentry skills through the centuries. In the more recent past, the International Style of architecture has embodied many concepts of DfD, albeit with significant failures regarding aesthetics, occupant control, and overall sustainability. From Le Corbusier's "Five Points of a New Architecture" to Mies van der Rohe's Barcelona Pavilion, the Modernist expression emphasized materials and form without decorative embellishments. Modern architecture often expressed a structure's assembly through materials

Fig. 6 Tipi or Tepee

Fig. 7 Ise Shrine

and methods of connection. A notable example is the Seagram Building in New York City (Seagram Building, 2006). With the utilization of pure materials such as metal, glass, stone and concrete, came their inherent reuse and recycling capabilities. The use of connections such as bolts emerged as key ingredients in Modernism that are also valuable as a potential deconstruction tradition.

Exemplified by the work of Richard Rogers and Renzo Piano, the "hi-tech" style of the Lloyds of London and the Centre Pompidou buildings also illustrate many DfD principles. These designs turn the traditional layers of internal core mechanical and utilities systems inside-out. Using structure as an armature upon which to place mechanical, plumbing and electrical systems, these designs provide for open flexible floor plans within the envelope of the building structure. As a matter of course, DfD is also integral to contemporary exhibition pavilions, entertainment structures and military facilities used for rapid deployment and temporary use. While these may be the most prevalent examples of current DfD practices, they can provide valuable concepts for the design of more permanent building types.

Fig. 8 Barcelona Pavilion

Fig. 9 Centre Pompidou

Corbusier's Points:

1- Le toit terrasse as a roof garden. The terrasse saves more room for the inside spaces; the garden maintains humidity.

2- La maison sur pilotis. The house is lifted above the humid soil and the garden is able to enter under the house. The view from the ground is no longer obscured.

3- La fenêtre en longueur. The window is the "élément mécanique-type" of the house. Some are fixed and some are mobile.

4- Le plan libre.
Structural walls are replaced by pilotis running through the house from ground to roof. The stairs become free.

5- La façade libre.
The pilotis are inside the house, the slab is cantilevered, the façade is free, the windows are no longer interrupted.

Le Corbusier's Five Points of a New Architecture, (Archiseek, 2006)

Fig. 10 temporary government shelter

Audience for this Guide

This guide is an introduction to the principles, methods, and materials of Design for Disassembly in the built environment. It is intended for owners, architects, designers and builders, and we hope it will help facilitate investigations and incorporation of this important aspect of sustainable design and building.

Factoids:

A study of building demolitions by the Athena Institute found that 70% of the buildings were between 51-100 years old and 30% of the buildings were less than 50 years old (O'Connor, 2004).

According to the US Census the average age of residential dwellings is 32 years old (US Census, 2004).

The US Department of Education estimates that the average school building is 42 years old and the majority of these are demolished at 60 years (NCES, 2000).

In “De architectura” or “On Architecture”, written by the Roman architect Vitruvius in the first century B.C., the fundamental principles of architecture were enshrined as: firmness, commodity and delight. These principles remain valid today. However they do not necessarily account for socio-economic trends in modern times. A survey of building demolitions over a three-year period in a major US city found that 57% of the building removals were for “area redevelopment” and “not suitable for anticipated use”, reasons that may have little to do with “firmness, commodity and delight” (Athena Institute, 2004).

Ten Key Principles for DfD

1. Document materials and methods for deconstruction. As-built drawings, labeling of connections and materials, and a “deconstruction plan” in the specifications all contribute to efficient disassembly and deconstruction.

2. Select materials using the precautionary principle*. Materials that are chosen with consideration for future impacts and that have high quality will retain value and/or be more feasible for reuse and recycling.

3. Design connections that are accessible. Visually, physically, and ergonomically accessible connections will increase efficiency and avoid requirements for expensive equipment or extensive environmental health and safety protections for workers.

4. Minimize or eliminate chemical connections. Binders, sealers and glues on, or in materials, make them difficult to separate and recycle, and increase the potential for negative human and ecological health impacts from their use.

5. Use bolted, screwed and nailed connections. Using standard and limited palettes of connectors will decrease tool needs, and time and effort to switch between them.

6. Separate mechanical, electrical and plumbing (MEP) systems. Disentangling MEP systems from the assemblies that host them makes it easier to separate components and materials for repair, replacement, reuse and recycling.

7. Design to the worker and labor of separation. Human-scale components or conversely attuning to ease of removal by standard mechanical equipment will decrease labor intensity and increase the ability to incorporate a variety of skill levels.

8. Simplicity of structure and form. Simple open-span structural systems, simple forms, and standard dimensional grids will allow for ease of construction and deconstruction in increments.

9. Interchangeability. Using materials and systems that exhibit principles of modularity, independence, and standardization will facilitate reuse.

10. Safe deconstruction. Allowing for movement and safety of workers, equipment and site access, and ease of materials flow will make renovation and disassembly more economical and reduce risk.

**Precautionary principle*

The precautionary principle, a phrase first used in English circa 1988, is the ethical theory that if the consequences of an action, especially concerning the use of technology, are unknown but are judged by some scientists to have a high risk of being negative from an ethical point of view, then it is better not to carry out the action rather than risk the uncertain, but possibly very negative, consequences. The principle is founded on standard risk theory, where risk is calculated on the basis of the probability of a harmful event occurring combined with the amount of harm caused if it occurs. The essence of the principle is that when probabilities cannot be calcluated with reasonable precision (i.e. it is a situation of uncertainty), then decisions that could potentially lead to great harm should be postponed or avoided. It is argued that in such situations, rational decision-making requires caution, in a generalisation of the ancient medical principle, codified in the Hippocratic oath, of “first, do no harm.”

Table 3. Precautionary Principle, http://en.wikipedia.org/wiki/Precautionary_Principle, visited April 10, 2006

Detailed Strategies

- Use high-quality reused materials that encourage the markets for the reclamation of materials.

- Minimize the different types of materials which reduces the complexity and number of separation processes.

- Avoid toxic and hazardous materials that increase potential human and environmental health impacts, and potential future handling costs, liability risk and technical difficulties.

- Avoid composite materials, and make inseparable products from the same material that are then easier to recycle.

- Avoid secondary finishes to materials which may cover connections and materials, making it more difficult to find the connection points.

- Provide standard and permanent identification of materials chemstry.

- Minimize the number of different types of components to increase the quantities of similar recoverable components.

- Separate the structure from the cladding to allow for increased adaptability and separation of non-structural deconstruction from structural deconstruction.

- Provide adequate tolerances to allow for disassembly in order to minimize the need for destructive methods that will impact adjacent components.

- Minimize numbers of fasteners and connectors to increase speed of disassembly.

- Design joints and connectors to withstand repeated assembly and disassembly to allow for adaptation and for the connectors to be reused.

- Allow for parallel disassembly to decrease the time on-site in the disassembly process.

Fig. 11 the double-headed nail in conjunction with metal hangers and plates creates a system that is more easily disassembled than traditional construction techniques

- Use a standard structural grid to allow for standard sizes of recoveable materials.

- Use prefabricated subassemblies which may be disassembled for reuse as modular units, or for efficient further separation off-site.

- Use lightweight materials and components that are more readily handled by human labor or smaller equipment.

- Identify point of disassembly permanently to reduce the time in planning the disassembly process.

- Provide spare parts and storage for them to allow for ease of adaptation and reuse of a whole component when only a sub-component part is damaged.

- Design foundations to allow for potential vertical expansions of the building in lieu of demolition.

- Use as wide of a structural grid as possible to maximize the non-structural wall elements.

- Consolidate mechanical, electrical and plumbing (MEP) systems into core units to minimize runs and hence unnecessary entanglement.

Fig. 12 C.K. Choi Building, University of British Columbia

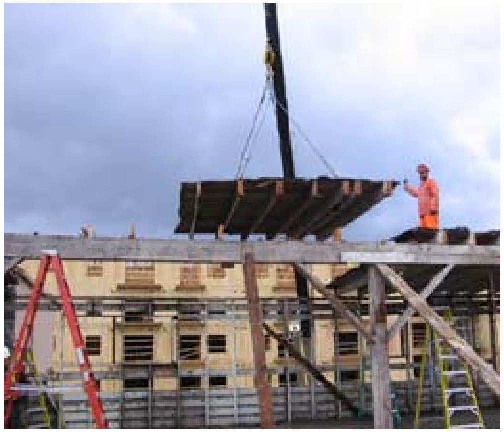


Fig. 13 panelization of roof structure

Fig. 14 theoretical disassembleable infill housing project

Selling the Benefits of DfD

DfD is a design paradigm that is intended to build in a manner that is environmentally responsible and engenders full-cost accounting. According to Wayne County, NC, in the context of waste management, "full-cost accounting… determines the full-cost of providing solid waste and recycling services by recognizing all direct and indirect up-front, operating and back-end costs." (Wayne County, 2006). Similarly, DfD recognizes that the "upfront, operating and back-end" costs in providing the services of the built environment should be considered in the initial building design. It incorporates the life-cycle of buildings, including end-of-life, into the decisions made before a building is built thereby increasing its value and effectiveness in the face of future use and costs. Some of its benefits include:

- Reducing resource-use and waste starting early in the building design process and as integral to the entire building life.

- Meeting market demand for flexible and convertible buildings, particularly speculative building types with high churn-rates (changes in internal spatial useage).

- Meeting owner-occupant building adaptation needs to accommodate future change, from adaptation to large-scale additions and subtractions.

- Maintaining value for resale to future building Owners who may wish to make adaptations or removals. This value is in the reduced adaptation and removal costs incurred by a future Owner.

- Allowing for ease of maintenance and repair of components and assemblies and enabling product leasing and take-back systems.

- Reducing toxicity in materials selection through a concern for reuse and recycling capability subsequently reducing potential worker and occupant exposure to environmental and health impacts from materials.

- Reducing potential future liability and waste disposal costs and burden to the community where the building is located.

- Insuring the future economic viability of managing materials from the use, adaptation and removal of buildings within the context of rising labor, equipment and fuel costs.

- Qualifying for Credit 8.C2 Adaptation, Renewal and Future Uses in the US Army SPiRiT Green Building Rating system and obtaining USGBC LEED™ Green Building Rating System Innovation credit(s).

- Implementing the Factor 10 concept (see sidebar) by using the services of design in lieu of linear materials-flow and energy-intensive systems.

- Enabling future adaptation and building removal that reduces the site environmental impacts of de-

FACTOR 10

"As less than 20 % of humankind consume in excess of 80 % of the natural resources at this time, the richer countries need to dematerialize their technical basis of wealth – or increase the resource productivity - by at least a factor 10 on the average."

Definition of FACTOR 10 to Achieve Sustainability (Schmidt-Bleek, 2003) structive demolition, such as dust, noise and mechanical equipment emissions.

- Preserving the embodied energy that is invested in building materials and facilitating the substitution of recovered materials for virgin resource-use.

- Making the deconstruction industry more cost-effective in the US by potentially reducing time and labor requirements which are currently the major impediments to the disassembly and recovery of buildings and materials, respectively.

- Enabling tax benefits to commercial building owners by the segregation of building components, enabling a classifications of personal property for building components with a much shorter depreciation life than as fixed real property.

Design Process

As with any design goals, DfD must be considered in each stage of the design. There are five stages in traditional architectural design.

Pre-Design – feasibility, market analysis, site analysis, community participation, environmental goal setting, building program development…

Concept Design – initial abstract formal design, site layout and location…
Schematic Design – dimensions, selection of structural systems, building code analysis…

Design Development – refinement of building dimensions, materials and systems, costs-analysis, value-engineering…

Construction Documents – development of final permit drawings, specifications, and insure code compliance…

The Pre-Design phase in traditional architectural practice can include building programming, environmental goal-setting, site analysis, feasibility or marketing studies, community participation, etc. Goals such as the “image” of a building or achieving the USGBC Leadership in Energy and Environmental Design (LEED™) rating can also be established in the pre-design stage. DfD and considerations for the life-cycle of the building would also be considered and prioritized at this stage. If the goal of DfD is chosen, it must then be maintained at each stage of the design process, and during construction.

A sample goal statement for DfD at the beginning of a project might be “the design of building interior elements, services, structure and site that allow efficient modifications to space layout, systems, building envelope, and footprint, and reduce waste during repair, renovation and deconstruction.”

The traditional building not designed for flexibility, adaptability and disassembly will be subjected to a simple relationship which is that as any new decision is made there are fewer options remaining, and the costs of changes and errors increases, depending upon the interdependence of affected systems. A building using DfD will reduce the cost implications of change in the design process, by reducing the physical interdependence of systems and increasing the simplification of systems.

A sustainable building design will include integrated design processes in order to optimize the operational efficiency of the building. Integrated systems design is a means to consider the interrelation of parts to one another and design structure, envelope, finishes, mechanical / electrical / plumbing systems in concurrently rather than as a series of lineal and isolated sub-designs. From this basis it is more likely that efficiencies can be gained from trade-offs between systems as a whole-building.

A simple example of integration and flexibility is the "limonaie". These structures (Fig. 15) are oriented on south facing slopes with tall vertical facades of stone columns. The roofs are a grid structure of wood members. In the summer the structural frame is left bare to allow the conservatory to function as naturally as possible. In the winter the vertical facade is infilled with glazing to allow low winter sun to penetrate and then capture the long-wave radiation in the interior to heat the space. The roof structural frame is covered with a simple plank roof to protect from snow and help retain the heat collected through the south-facing glazing.

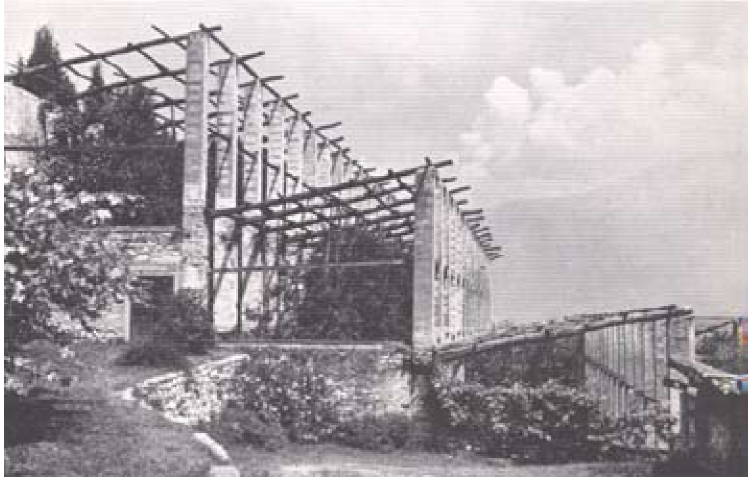


Fig. 15 "limonaie" convertible conservatories

Fig. 16
CK Choi building

CK Choi Building

"The building houses the Institute for Asian Research at the University of British Columbia. With five program areas..., the Institute's research activities change every few years. In addition, much of the faculty is composed of visiting professors... resulting in a high turn-over rate. Therefore, the building's design allows for flexible classroom spaces via the use of panelized walls that allow rooms to grow and shrink as research needs change. A plan was also developed... that gives each program area its own atrium and an open staircase to their second-floor offices. Within these areas, the plan accommodates flexibility of uses... Recognizing that technology changes rapidly as well, state-of-the-art wiring was incorporated that can be easily accessed for modifications through a molded raceway. Adaptability is also built into the roof, which is designed for the future accommodation of photovoltaic (PV) panels for electricity generation when the cost of this technology comes down." (Wilson et al, 1998)

Design Strategies

In the words of Stewart Brand, a building designed to be adaptable and disassemble-able is "scenario-buffered" (Brand, 1994). In the context of DfD, this means that it can accommodate multiple uses, technologies, tenants, and environmental stresses during its life and can more readily accommodate disassembly and materials recovery at end-of-life. Scenario planning envisions multiple lives for a building from which the most likely DfD strategies can be developed. In order to fully develop potential scenarios, the participants in scenario-buffered planning should include the architect, the owner, the property managers and facilities managers of the building, and key tenants. Incorporating DfD is a means to implement a "buffered" building that will minimize the cost and impacts of change and mitigate the friction between the original building design and alterations.

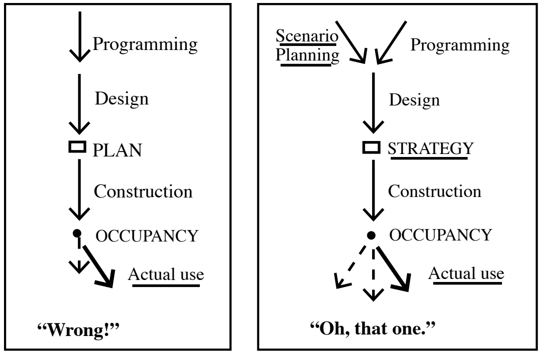


Fig. 17 scenario planning (Brand, 1994)

If nothing else, to consider the building design as a strategy rather than as a static object will move the design-thinking to consider that the "construction" of a building does not stop at the finish of the initial construction and that the building will have a dynamic life. To use an analogy, a design is the DNA code for a building. This DNA has all the information needed to form the building, but by default or intention will also determine how the building is operated, maintained, repaired or remodeled, renovated, and how it can meet a graceful end as resources for the next generation of building.

Design Process Strategies

- The lead designer should provide a briefing on DfD to each team member and discuss their role collectively as part of a team and within their individual specialties.

- The best use of DfD can be investigated through a life-cycle cost analysis based on the initial building use and with consideration for a 50 year time-frame or greater, depending upon building type.

- Evaluate site constraints, project budget, building functions, proposed lifespan and the proposed construction delivery process as crucial determinants of DfD goal-setting.

- A large part of DfD will be realized in mechanical systems and in structural systems, and these consultants must play a large role in the development of the design. Two fundamental concepts relative to these areas are to "design out" active services and replace these with passive measures that have a longer life-span, to detail structural connections (within code compliance) to be as accessible and disassemble-able as possible, and to make structural systems that are as multi-functional as possible.

- Targeting specific assemblies and components for materials recovery and reuse and including potential reuse categories for these elements in a deconstruction plan will help inform design decisions.

- For the reuse of existing materials into the DfD design, undertake a detailed cost-benefit analysis of low-cost design-for-reuse options.

- Consider any aesthetic issues that either are preconceived or that will result as a product of a DfD design element and insure understanding of the implications as the design progresses – for the client and the contractor and sub-contractors.

- Use three-dimensional drawing to aid the process of DfD and as a direct design tool to model both the assembly process and also the potential disassembly process whether for partial disassembly as part of a renovation or a full deconstruction sequence.

- Consider that DfD detailing may be much more explicit than in some traditional construction drawing documentation.

- Develop a comprehensive Deconstruction Plan early on - otherwise reusable building elements may be destroyed unnecessarily.

- Allow extra time from the beginning of the project to ensure that DfD is fully incorporated.

- Aim to bring the whole project team and the client on board with the idea of DfD from the beginning of the project.

- Audit contractors and ensure that initial briefing and training for DfD has taken place.

- Carefully add all alterations to drawings and specifications so that there is an integrated set of "as built" drawings for maintenance and deconstruction purposes. (Adapted from SEDA, 2006)

Strategy for Reuse or Recycle

The goals of design for reuse and design for recycling are not interchangeable because design for reuse is generally preferable to design for recycling. Reuse dictates that components and materials can be removed intact and maintain service and aesthetic qualities with minimal alterations. Design for recycling on the other hand, can utilize destructive disassembly processes that much more degrade the materials, as long as this does not result in unacceptable levels of contamination and commingling that prevent economic further processing into the new materials' feedstock (SEDA, 2006).

Design for deconstruction is most effective when it allows for maximum flexibility of spatial configuration within a given structure, as this preserves the building structure as a whole. Beyond this, designers need to think about "future-proofing" their details in such a way that maximizes the possibilities for both building assemblies and their sub-components to be reused in other buildings as far as practicable. Only if neither of these strategies is established as practical, following a cost-benefit analysis, should designers resort to a recycling-only strategy (SEDA, 2006).

Fig. 18 team meetings are essential to a succesful and integrated DfD strategy

Hierarchy of Building Resource Management Goals

1. Adaptive reuse of existing building incorporating DfD for future adaptation.
2. DfD for adaptability and longevity of new buildings.
3. Reuse of building assemblies.
4. Reuse of building components.
5. Remanufacture of building components.
6. Reuse of building materials.
7. Recycling of materials.
8. Reclamation of energy from building elements, components or materials
9. Biodegradation of building materials
10. Landfill sequestration for future resource / energy recovery

Building Resource Management Hierarchy, Adapted from SEDA, 2006.

Within the hierarchy of goals described above for optimizing materials resource-use, there are potential metrics for economic and social benefits, resource-use, and pollution prevention and waste avoidance that can be incorporated into DfD. Methods to assign value of DfD in general and for specific building systems can include those listed in the values of DfD.

Values of DfD

- Environmental impacts and traditional waste per and by total quantity used in a building.

- First costs savings from use of less materials and allowances for errors in construction.

- Future costs savings from dismantling processes, waste disposal and replacement of components and materials.

- Likelihood of changes to particular systems from wear, spatial needs, and aesthetic preferences, technological or other efficiency upgrades.

- Projections of organizational trends, and larger demographic, land-use or economic trends that will impact upon the building.

- Focus on the reduction of predicted operational and maintenance costs – particularly labor costs.

- DfD strategies that enable other high-priorities such as aesthetics, user-defined “mission”, sustainable building practices including energy and water efficiency, indoor environmental quality, etc.

- Directly meeting use and building typology requirements forflexibility or demountability.

- Particular spatial needs in the context of a building user’s organizational patterns that will be impeded without DfD.

- Building in high-risk environments where DfD constitutes risk management in the face of potential catastrophic damage to discrete elements of a building and resulting loss of function, creation of waste, and high costs of repair and replacement.

The Design Team

A request for qualifications for the design team will state the scope of the project, the client's vision for the project including DfD design benchmarks as well as other sustainable design benchmarks, and the nature of design services needed (AIA, 2006). A request that incorporates DfD specifically in the design goals might also include a rationale for DfD based on the client's mission or other motives. Since DfD address specific issues such as building uses that are intended for short-life, functional change expectations or rapid churn of certain aspects of the building, all of these issues are important for the designer to know.

If DfD is to succeed, the whole project team and client must be in agreement from the beginning of the project. Different stakeholders in the team will have different objectives and it is important to identify how far DfD can satisfy these and to establish priorities, procedures and lines of communication relating to DfD throughout the design and construction process and then for the future building use and eventual deconstruction.

Phase	Client	Designer	Contractor
Pre-Design	Support scenario planning. Hire an architect who is experienced in sustainable design and DfD. Brief the design team on critical requirements for upgrading, adaptability and flexibility in use. Stipulate "as built" drawings and specifications as part of the design contract.	Conduct integrated scenario planning and programming. Demonstrate best practice of DfD to client. Investigate DfD relative to building type and client needs. Develop goals and priorities for DfD including which building elements are most cost-effective to DfD.	
Concept Design	Engage contractor as expertise on design implications for DfD.	Organize meetings with the contractor and major vendors to identify reused materials and construction processes which support DfD.	Obtain initial briefing and training on DfD.
Schematic Design		Carry out a design check by producing an outline plan for the deconstruction of the building and ensuring that the design proposals are consistent with this form of reverse engineering.	Advise the design team on deconstruction processes, potential salvage and reuse priorities, and recycling requirements for various material types.
Design Development		Produce a detailed plan for the deconstruction of the building.	Advise design team on implications for deconstruction in relation to design and detailing (where possible).
Construction Documents		Insure details have been implemented to not compromise their DfD integrity. Incorporate plan for deconstruction into drawings specifications. Insure bid documents reflect commitment to DfD construction.	Advise the design team on implications for construction and deconstruction of design and detailing (where possible). Identify good construction practice to promote DfD and advise design team accordingly. Advise design team on 'plan for deconstruction' drawings and specifications.
Construction Administration	Ensure that all maintenance staff and contractors are fully briefed on DfD strategies. Allow for additional time in contract period for construction to insure DfD through careful practices.	Create or update the construction documents to create comprehensive "as built" documents.	Insure quality of workmanship to maintain integrity of DfD details as designed. Train sub-contractors as necessary.
Facility Operation Services	Monitor the performance of project over time (where possible) and build in the evaluation into future DfD.	Insure that all maintenance staff and are fully briefed on DfD strategy, and instigate a feedback strategy on building performance from DfD.	

Roles and Responsibilities by Design Phase, Adapted from SEDA, 2006.

The Deconstruction Plan

Even the best DfD will not be realized if the building constructors, operators, and deconstructors do not understand how to implement the disassembly processes as they were intended. Therefore, an important element of the DfD process is the documentation and dissemination of the building's design intent per its materials, components, connections and form.

Visual transparency of materials properties and connections can provide a substitute for separate written or graphic instructions for dismantling, handling, treatments and reuse / recycling options for components and materials. Direct materials labels or imprints, etc. can be used to communicate materials' compositions and properties similar to the imprinted number code for plastic products. Where the direct visual display of information is not possible, then other forms of recording information must be used. Perhaps in the future, all building products can be made with radio frequency identification (RFID) tags built into them, in which case information can be retrieved either directly or in the form of a code that references a separate database. With wireless technology, a component or assembly could then be scanned and the information regarding materials, connections, assembly process and disassembly instructions can be readily retrieved.

At this time, current methods of documentation rely on construction documents and "as-built" documents. This initial documentation effort will be of little utility unless each future modification is also recorded. On the other hand, the DfD and any future adaptation or disassembly will be greatly compromised if alterations over the building's life cause the original DfD elements to no longer function. Therefore, the Deconstruction Plan should also be updated to mitigate the deconstructor's need to "start from scratch" to understand the building.

A comprehensive Deconstruction Plan will insure that designed-to-be-reusable building elements will be recovered as intended. The Plan should be issued to all parties at the outset of the building contract to ensure a construction process that does not compromise the DfD and Deconstruction Plan. For a successful Deconstruction Plan, which is a part of the overall DfD detailed plan, make sure the following tasks are undertaken:

1. Statement of strategy for DfD relating to the building

- Demonstrate the strategy behind the designed re-usable elements and describe best practice to ensure they are handled in a way which preserves maximum reusability.

2. List building elements

- Provide an inventory of all materials and components used in the project together with specifications (including Material Safety Data Sheets as applicable) and all warranties, including manufacturers' details and contacts.

- Describe the design life and/or service life of materials and components.

- Identify best options for reuse, reclamation, recycling and waste to energy for all building elements. This may include both reuse and recycle options and also the infrastructure options. This may change between time of construction and time of deconstruction so

3. Provide instructions on how to deconstruct elements

- Provide up-to-date plans for identifying information on how to deconstruct buildings.

- Where necessary add additional information to the "as built" set of drawings to demonstrate the optimum technique for removal of specific elements.

- Describe the equipment required to dismantle the building, the sequential processes involved and the implications for health and safety as part of the management requirements.

- Ensure that the plan advises the future demolition contractor on the best means of categorizing, recording and storing dismantled elements.

4. Distribution of DfD Plan

- Revise the plan as necessary and reissue to all parties at the building completion stage, so that there is maximum awareness of the DfD requirements for the future, including building owner, architects and builder.

- Place copies of the revised Deconstruction Plan with the legal documents of the building, and any building commissioning, or operations and maintenance files.

(Adapted from SEDA, 2006.)

Fig. 19 IKEA House

For an example of a model deconstruction specification that would be used to develop the deconstruction contract at the building end-of-life, see the Model Deconstruction Specification section of this guide.

Building Design

Just as meeting energy-efficiency or other sustainable design goals for a building requires prioritization of the most feasible and cost-effective strategies, incorporating DfD will require prioritization of applicable strategies as well. Design for Disassembly is most effective when it allows for maximum flexibility of spatial configuration within a given structure, as this preserves the building structure as a whole. Beyond this, a designer can think about DfD for whole-building disassembly to enable building assemblies and their subcomponents to be reused in other buildings as far as practicable. (SEDA, 2006). Clearly there are individual hierarchies of resource-conservation, technical feasibility, and economic efficiency which may not always align.

Buildings Have Different Life-Spans

Certain buildings will have service-lives based on function and economic parameters of use. A temporary building intended for an exhibit is designed to be least-cost and for a single defined use. A residential structure may be located in a context which preserves its integrity, such as an established residential area, but nonetheless may be demolished for other reasons, such as a "tear-down" to build a larger structure to meet functional needs or just investment-based criteria.

Civic and monumental building types may be subjected to economic pressures based on location but at the same time contain certain cultural values that have high-value and may attain iconic statue that ensure that they resist demolition or removal. Theystill fare better functionally and economically with elements of adaptability for system, component, and materials alterations and replacements. Apart from certain external forces, such as a community's economic trends, building types do have predictive life-spans based on norms of use and investment.

Building Elements
Have Different Life-Spans and Costs

Although not yet commonly used in sustainable building design ratings such as LEED™, whole-building life-cycle analysis (LCA) is a means to model building materials design decisions including DfD. Life-cycle cost (LCC) data is typically available for standard components, and their service or technical life-cycles can be a valuable source of information for the consideration of DfD. In the absence of these rigorous analyses, there are other ways to approach DfD prioritization for a particular building type such as residences. Using data from the American Housing Survey, it is possible to consider the average changes that residences undergo. As noted in Table 10, there are certain use-functions or individual components that require larger expenditures per alteration or renovation. Clearly from an economic standpoint it would be worth considering DfD for those elements that incur the greatest costs per change.

Another practical consideration for residences is the sheer magnitude of alteration or renovation projects performed in an average year. While kitchen renovations incur the highest cost per project, floor finish alterations or replacements are the greatest number of projects undertaken. Interestingly enough, according to the US Economic Census, the used flooring industry grew 60% by volume of sales between 1997 and 2002. As a comparison, the general retail building materials and used merchandise industries each only grew about 29% during the same period (US Economic Census, 2003). Clearly then there is a market for finish flooring systems that are easily disassemble-able, as realized by many carpet manufacturers who have developed carpet tile systems for both commercial and residential applications.

Category	**Design Service Life**	**Examples**
Temporary	up to 10 years	• Non-permanent construction buildings, sales offices • Temporary exhibition buildings
Medium Life	25 to 40 yeasrs	• Some industrial buildings • Parking structures
Long Life	50 to 90 years	• Residential, commercial and office buildings • Health and educational buildings • Industrial buildings
Permanent	minimum 100 years	• Monumental buildings (ex. museums, art galleries, archives) • Heritage buildings

Typical Building Lives Based on Typology Adapted from (Durability Implications, 2006)

Materials Lives

A basic determinant of DfD emphasis will be the technical and service lives of the materials that make up a building. The technical life of a material is the life that the material will have independent of any consideration for use, including human and environmental stresses, obsolescence cycles, etc. The service life is a predictive life based on how the component is intended to be used. While the technical life is a potentially longer life-span, it will typically be the service life that determines an "actual" life. One of the fundamental concepts of DfD is the separation of longer and shorter-lived components and materials. By focusing on the points of connection between separate systems that have the most disparate service lives, DfD can have very practical and economically valuable impacts. Repair and replacement cycle information can be used to identify the most critical connections between building assemblies and components where the greatest life-span friction will occur. The table on the next page illustrates typical repair and replacement cycles for some common materials which can easily assist in; 1) selection of materials and 2) providing focus for effort on DfD connection detailing to have the greatest benefit.

Type of Project	**Avg / Project**
Kitchen Addition	$ 15,400
Remodeled "wet" room	$ 9,266
Altered or renovated "dry" room	$ 8,100
Bathroom addition	$ 4,900
Siding (add or replace)	$ 4,100
Roofing (add or replace)	$ 2,900
Other jobs (add or replace)	$ 2,900
Porch / deck additions	$ 2,500
HVAC / ducts (add or replace)	$ 2,500
Doors or windows (add or replace)	$ 1,600
Paneling / ceiling / flooring (add or replace)	$ 1,500
Insulation (add or replace)	$ 600
Electrical wiring, fuse boxes (add or replace includes security)	$ 550
Interior water pipes (add or replace)	$ 500
Plumbing fixtures (add or replace)	$ 450
Water heater (add or replace)	$ 400

Average Cost per Residential Repair or Renovation, Adapted from the Supplement to the American Housing Survey, 2001

As an example, the replacement cycle for a clad wood window might be 25 years whereas the replacement cycle for brick cladding is 75 years. Clearly the detailing at the joint between these two components

Type of Project	**Percent**
Interior floor finish	20.42 %
Electrical / Plumbing	11.84 %
Doors and Windows	10.21 %
Interior walls alteration w/ plumbing	9.21 %
HVAC equipment	8.56 %
Fixtures	8.31 %
Roofing	7.76 %
Interior room alteration (dry)	7.06 %
Exterior addition	5.08 %
Interior wall cavity	3.50 %
Exterior wall cavity	3.32 %
Exterior siding	2.80 %
Interior wall / ceiling finish	1.94 %

Percentage of Projects per Type per Year Adapted from the Supplement to the American Housing Survey, 2001 should allow for ease of removal and replacement of the window without requiring alteration to the brick.

Materials - At the base level of reuse or recycling, the chemical and physical properties and inputs of craft and production of a material will define its economic value, toxicity, durability, flexibility for reuse or its purity for a recycling process. If a material is designed to maintain its structural integrity and composition it will have the greatest utility for reuse, even if it is not necessarily recycled. Many "wet" materials are not feasible for reuse such as concrete, asphalt paving, mortars or paints, but may be recycled or at least not contaminate other recyclable materials that are associated with it. If a material is not designed as an independent or "dry" component, then it should be chosen and fabricated as a viable input to a recycling process and these properties communicated from design to construction to use.

Building Materials Types	Repair (yrs.)	Total Replacement (yrs.)
Flat roof BUR membrane	10	20
Pitched roof, cement composite shingles	20	50
Pitched roof steel sheet	usually not required	30
Brick cladding	25	75+
Acrylic stucco	20	?
Interior gypsum board	3 to 10	25
Interior concrete or block	10 to 20	75+
Metal or vinyl windows	10 to 20	40
Clad wood windows	10 to 15	25 to 50
Solid wood interior doors	4 to 8	15
Metal doors	5 to 15	25
Terrazzo	0 to 15	60+
Ceramic floors	10 to 15	40+
Vinyl composition tile	8 to 15	20
Hardwood floors	5 to 10	40+
Carpet	3 to 8	5 to 15

Repair & Replacement Cycles for Typical Building Materials Santa Monica Green Building Program

Connection – At the connections level, a material may be able to be taken back to its constituent properties or remain embedded within components or assemblies. Connections will be a large factor of on-site disassembly processes and as such require access, readability, and simplicity in terms of tools and actions that are required to work on them. The scale of connection will be an important determinant of whether manual labor can be used and the economies of transport. While clearly fewer components of larger size will minimize the number of connections and hence labor to assemble a building, the flexibility of the component may be low for reuse or recycling without further disassembly. If the connection is inaccessible or difficult to understand as a process, then this will make the disconnection process inefficient or prohibitive.

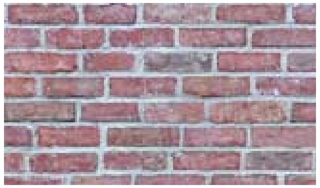


Fig. 20 brick

Fig. 21 unfinished wood siding

Form and Structure – As will be noted in the case studies section, DfD has certain forms that are more efficacious, such as a grid post and beam, open span with exterior bearing elements, and simpler forms where structure is consolidated into fewer points or planes, and overall complexity is reduced. A post and beam system, combined with exposed connections and minimal partitioning elements will result in an expression that will communicate the visual data about the building's disassembly potential. Where machinery is more likely to be used in the construction process, then panels or large members can be used, whereas if the likely deconstruction will utilize less mechanical labor, then smaller and more members will fit this process (Webster, 2006).

Fig. 22 connection detail 1

Fig. 23 connection detail 2

Type of Connection	Advantages	Disadvantages
Screw	easily removable	limited reuse of both hole and screws cost
Bolt	strong can be reused a number of times	can seize up, making removal difficult cost
Nail	speed of construction cost	difficult to remove removal usually destroys a key area of element - ends
Friction	keeps construction element whole during removal	relatively undeveloped type of connection structural weakness
Mortar	can be made to variety of strengths	mostly cannot be reused, unless clay strength of mix often over-specified making it difficult to separate bonded layers
Adhesives	strong and efficient deal with awkward joints variety of strengths	virtually impossible to separate bonded layers cannot be easily recycled or reused
Rivet	speed of construction	difficult to remove without destroying a key area of element - ends

Connection Alternatives for Deconstruction, Adapted from SEDA, 2006.

Type of Structure	Advantages	Disadvantages
Masonry	• individual components break down into small, easily reusable units • solid mass can be re-cycled if monolithic • re-use does not dictate design	• blocks need soft binder to be reused which reduces strength • may include reinforcement which is harder to deconstruct • requires heavy machinery to break down solid mass • may have lateral walls which compromise long term occu¬pancy pattern options
Light Frame	• structurally efficient, allows for multiple occupancy patterns • easy to deconstruct into reuseable elements if detailed appropriately (not concrete in-situ) • can be layered separately from cladding and insulation • can be factory made (not concrete in-situ)	• difficult to deconstruct unless framework is detailed with appropriate joints • notching, holes and binding with resins can reduce possibilities for re-use • depending on size and type can be manually or mechanically deconstructed
Panel System	• structurally efficient • factory made – gives precision • all components can be built in to minimize waste	• required mechanical deconstruction • materials are bound together and hard to separate • need for cross wall bracing reduces internal options
Post and Beam	• separates structure from envelope and other systems, can provide standardization of dimensions and homogenous materials • can reduce mass of structure to fewer linear components	• fewer larger members require mechanical deconstruction. • less multi-functionality is possible such as combining structure with finish, etc.

Major Structure Systems Related to Deconstruction (Adapted from SEDA, 2006)

Design Summary

The following detailed tasks should be carried out at each stage of the design to ensure that the DfD strategy is carried through at all levels:

Pre-Design

- The lead person in the team should provide a full briefing on DfD to each team member and discusses their role both at collective team meetings and on an individual basis.
- Cost estimators need careful briefing on the cost-benefit implications of DfD both in terms of initial construction costs and future maintenance costs.
- Mechanical engineers should be encouraged, in consultation with the rest of the design team, to design out as much as possible of the active servicing elements in a building and replace these with passive measures that have a longer life-span.
- Structural engineers should ensure that their structural systems are easy to deconstruct and designed for maximum reuse.
- Other specialists should be briefed and consulted on DfD strategies as necessary
- Establish DfD targets and benchmarks in terms of the percentage of the building that can be reused as well as the potential reuses for each existing element.
- Evaluate site constraints, project budget, the purpose of the building, its lifespan and the contract period as crucial determinants of DfD benchmarking.
- It is vital that an accurate survey is carried out for existing buildings to identify existing DfD opportunities e.g. preserving the ability to remove existing joists easily.
- Ensure that a renovation does not compromise the deconstructability of an existing building.
- Once all these tasks have been achieved the results should be fed into an overall DfD strategic plan for the project.

Concept and Schematic Design

- Adopt the principles for DfD outlined in this guide as well as other guidance on sustainable design as far as possible; aim to prioritize key principles.
- Cost estimators to undertake a detailed cost-benefit analysis of low-cost DfD options.
- Evaluate the structural and service options which can maximize DfD within the given constraints.
- Agree on a list of value-engineering options, which take DfD into account, should the project costs exceed the budget.
- Make sure the aesthetics for the project, which are clearly defined at this stage, take account of the agreed DfD strategic plan; so that any aesthetic conflicts that may arise do not come as a surprise.

Design Development and Construction Documents

- Use the DfD analysis from the Pre-Design phase as a framework to develop the details and specifications in tandem with CDM requirements.
- Seek advice from manufacturers on whether, and how, product value can best be maintained through reuse and how products can be certified for reuse.
- Where it has been possible to identify reusable elements from other buildings, incorporate these in the detailing, provided they do not violate the overall DfD strategy.
- Develop the strategic DfD plan to a more detailed level to take account of drawings, specifications and

costs, as part of an iterative process of design.

- Carefully develop specifications, to ensure that the DfD is not compromised by poor specification of materials, finishes, joints and connections.
- Use three-dimensional drawing to aid the understanding of the process of DfD - it reveals hidden aspects of two-dimensional drawing in terms of the construction/deconstruction process.
- Fully detail mechanical / electrical / plumbing drawings rather than specifying in outline to ensure full coordination for DfD.

Construction Administration

- Once the contract has been awarded, ensure that pre-site start meetings allow time for a thorough briefing and negotiation on the objectives of DfD as part of the project and the most effective means for achieving this.
- Encourage the design team and contractor to use local or national directories to reclaimed materials to source reclaimed materials locally.
- Ensure any alterations to the digital drawings and specification are carefully integrated into a revised set of drawings so that a genuine set of "as built" digital drawings is available for maintenance and deconstruction purposes.
- Provide a comprehensive and digital operating and maintenance manual for the building, complete with logbook to record future maintenance, carefully cross-indexed to aid rapid information retrieval.
- Ensure the manual contains a complete section on the DfD strategy as well as the revised "as built" deconstruction plan and drawings.

Facility Operation Services

- The client and all parties should make a clear commitment to obtaining feedback from the outset of the project. The following tasks will assist with this.
- Provide a contingency budget for changes which occur during building commissioning and future maintenance, and the recording of these in the logbook, the deconstruction plan and on as-built drawings.
- Provide for continuing dissemination and transfer of DfD-related information during the life-span of the building to all parties concerned which takes account of any transfer of ownership or upgrading of the building.
- Training for both the users and maintenance team on the DfD aspects of the building will help to prevent maintenance choices which disable the DfD function; this is vital if the DfD strategy is going to work effectively.
- Undertake post-occupancy evaluations and post-project appraisals to learn if aims of project have been met.

Ownership and Future Responsibilities

Underlying the diversity of building design and construction strategies is one imperative to ensure successful DfD – a sense of continuing "ownership" by the original designer and contractor.

Possibly the most important economic benefit to DfD is to design buildings that are "harvestable" stores of valuable future resources. If this paradigm shift is not achieved, there will be no real incentive to ensure that the knowledge about the building, and the changes it undergoes, remains coherent over its complete lifespan and facilitates intelligent resource use (Adapted from SEDA, 2006).

The Six S's According to Stewart Brand

Using the nomenclature and framework originated by F. Duffy and modified by S. Brand in his 1994 book, "How Building's Learn," the following case studies and products are described using the six S's system of *Site - Structure - Skin - Services - Space Plan – Stuff* (Brand, 1994). These categories are meant to help describe buildings as "shearing layers of change" that are in constant friction. The faster-changing layers such as the Space Plan are controlled by the slower changing layers such as the Structure, which are less flexible, thus creating friction between them. For example, an interior Structural element that can only be moved as a part of the whole building reconfiguration will dictate the limits of non-structural Space Plan changes. If the Space Plan configuration that is needed to optimize the function of the building cannot be accommodated because the Structure will not allow it, this high degree of friction could cause the premature obsolescence of the entire building. In order to avoid these conflicts, both in use, and as a means to facilitate end-of-life disassembly, the consideration that building assemblies have cycles of use and wear can help designers plan for change with minimal building dysfunction, cost and waste.

In the building case studies, Stuff has not been included as it is the non-built artifacts such as furniture that is not attached to buildings. The Stuff category is however used in the descriptions of components and materials, as they are still a large part of the building product library. The building case studies are not meant to be inclusive, but representatives of buildings that can highlight some positive and negative attributes relative to DfD. Likewise, the components and materials that are illustrated are also not meant to be exhaustive but to illustrate commercially available systems that have some attributes that are compatible with DfD. Components and materials have been chosen based on different factors relating to DfD such as low-toxicity or an aspect of "dematerialization." Dematerialization is defined as an absolute or relative diminution in use of nature per unit utility or service (Factor 10 Manifesto, 2006). In simpler terms it is to provide the same ends using less resource than current practice. These ends can be direct such as building automobiles using higher-strength lighter-weight materials, than is the norm, or indirect such as the so-called "product of service" concept. This concept has been most applied in the floor-covering industry to promote leasing and take-back programs as providing the "service" of floor covering rather than the material goods themselves.

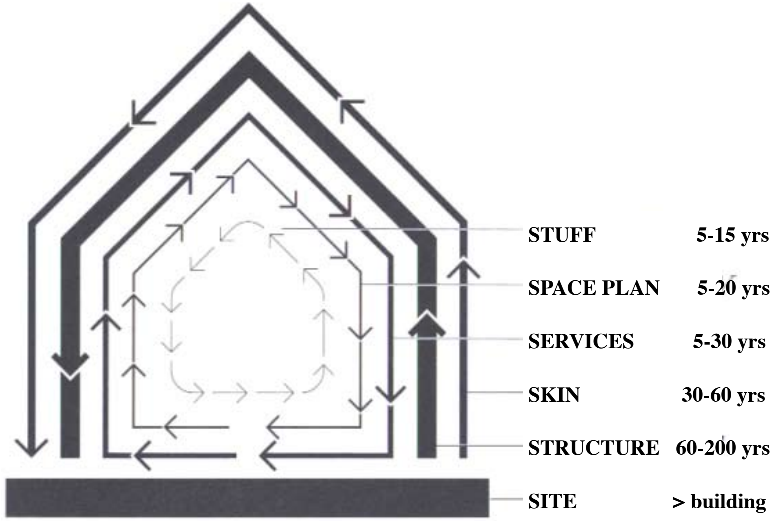


Fig. 24 Stewart Brand's Six S's diagram

Shearing Layers of Change

- ***Site*** (geographical setting, urban location, legally defined lot) can easily outlast the life of the building.

- ***Structure*** (foundation and load-bearing elements) can last 30-300 years although many buildings don't live that long for other reasons.

- ***Skin*** (the building envelope, consisting of frame, exterior finishes, glazing, etc.) can change for repair or appearances every 25 years or so.

- ***Services*** (the utility and HVAC systems and moving parts like elevators) may reach the point of major replacement every 7-15 years and can cause demolition of an entire building if their embedded-ness prevents alteration.

- ***Space Plan*** (division of space, cabinetry, interior finishes) can range widely from a commercial setting being overhauled every three years to a much longer life in a residential setting.

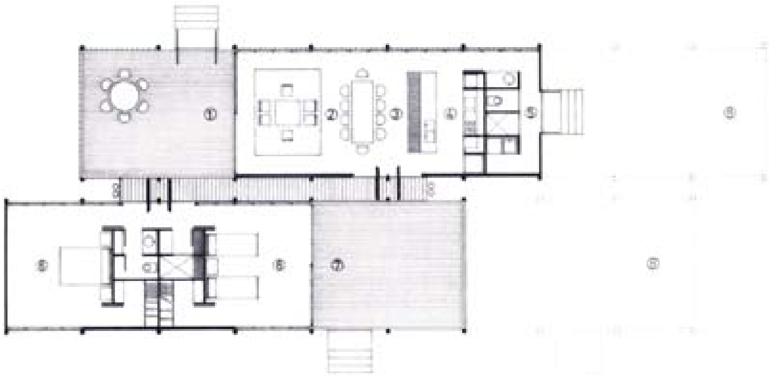
- ***Stuff*** (furniture, free-standing lamps, appliances, etc.) the things that change daily to monthly.

(Brand, 1994)

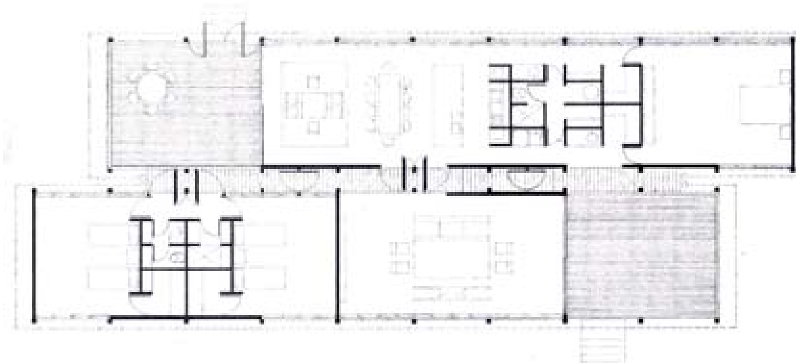
Residential

- ***Marie Short House***

Australian architect Glenn Murcutt produces residential architecture in the temperate regions of Australia that exemplifies elements of DfD. By request of the client, the Marie Short House was specifically designed with the capabilities of adaptation, disassembly, mobility and reassembly in mind.



1975 plan



1981 plan

Fig. 25 1975 original plan and 1981 adapted plan of Marie Short House

Site: With a purity of materials expression, Murcutt incorporated the ancient Aboriginal concept of touching the earth lightly in the site design of the Marie Short House. This is interpreted literally by the use of a pier foundation and raised-floor system. The house is also oriented on the site to maximize passive ventilation and solar design benefits, reducing requirements for mechanical systems for heating and cooling.

Structure: The building employs post and beam construction in a single-story, which allows for an open floor plan within a modular structural grid. The use of a grid system allows for expansion in any lateral direction. In fact, the building was expanded using this grid framework in 1980. To do so, the gables and verandahs of the original building were dismounted and placed at the new extended building ends. The use of dry structural connection details, including bolts, made the dismantling process and reconstruction possible with limited to no waste. Lateral stability is provided by diagonal steel tension rods, minimizing materials use for this function while also creating an expressive element.

Skin: The building envelope maximizes the use of the natural elements, sun and wind, through various methods of glazing and fenestrations. Infill panels for skylights, adjustable louvers, and moveable screens made from lightweight materials are all elements that aid in the passive systems and enhance the operability of the building with minimal reliance on sealants, caulking, and gaskets. All materials used within the design were locally available.

Services: The services for this house are in effect manifested by the site, structure and skin through the use of passive systems incorporated within these elements. The roofing system utilizes natural convection to effectively ventilate the house. In addition, the plumbing systems are consolidated into core zone(s), thus minimizing runs.

Space Plan: Featuring mostly raw materials, a minimalist approach is taken to the interior spaces, drawing on the natural light, fresh air and aro¬matic surroundings, as a “dematerialized” approach to fill the spaces.

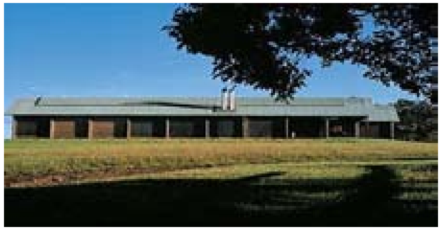


Fig. 26 *Marie Short House* south elevation

Fig. 27 interior

• *Two-Family House*

The Austrian firm KFN Systems’ range of pre-fabricated building types are representative of a recent trend in modernist pre-fabricated residential projects. Their designs include mobile dwellings like the FRED and the SU-SI as well as more permanent structures such as the Two-Family House. The three-dimensional timber-framing modules used in the house are designed to be configured both horizontally and vertically up to four stories. Afterward, the exterior envelope and interior panels are installed to complete the basic building structure. The two dwellings are created by stacking identical floor plans within the framing modules.

Site: The Two-Family House uses a slab-on-grade foundation. This is the antithesis of a pier and footing foundation, but at the same time the slab-on-grade combines foundation and floor structures into one system. Site construction impacts are greatly mitigated from the use of pre-fabrication for all major assemblies including the kitchen and bath units.

Structure: The modular timber-frame is based on a 5m x 5m x 2.7m (16.4' x 16.4' x 8.8') three-dimensional grid that can be combined as building blocks in multiple variations of form and size. The independence of structure from building envelope and interior finish systems allows for flexibility and convertability of the building design.

Skin: The design of the 5m x 5m horizontal grid breaks down to be equivalent to an 8" increment if using US dimensions and standard building product sizes. This is a reasonable scale to allow for flexibility in the exterior panel customization. The KFN Systems design utilizes ten fundamental exterior panel designs thus creating a building envelope with adjustable patterns of varied fenestration and material types, while still using standardized components.

Systems: The kitchen and bathrooms units in the house are pre-fabricated and delivered to the site. They are located in the core of the building, and given that the dwellings are identical, the wet core is stacked vertically, limiting the runs of service systems throughout the house. The design also utilizes chases for utilities thus minimizing the entanglement of these service systems within other assemblies such as the interior walls and exterior panels.

Space Plan: The ceiling and floor systems are panelized along with the wall assemblies of the building. The building finishes and many interior fittings maintain the homogeneity of wood as the dominant building material.

Fig. 28 off-site construction of panels

Fig. 29 infill panel

Fig. 30 after construction

Fig. 31 basic plan of Two-Family House

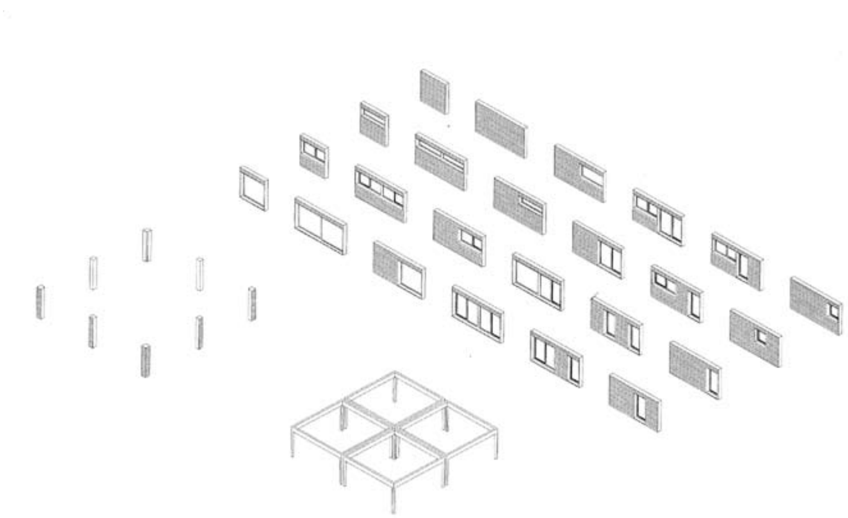


Fig. 32 structural system and infill panels

• *OPEN_1 House*

The OPEN_1 House is a product of Bensonwood Homes, a New Hampshire-based design/build timber-frame company. The Open-Built™ System use in the OPEN_1 House, explicitly uses the framework of the Brand six "shearing layers of change". The fundamental premise of the Open Built™ System is "disentanglement." By designing in 3-D and distinguishing 3-D space for each system in the building, the design focuses on each subsystem and separates it physically from any other subsystem. Where wiring or piping is embedded in walls, then access is provided in the surface of the wall. These sub-systems can be upgraded and repaired over time without altering or compromising the building's structure. The Open-Built™ system is based on components and as much off-site prefabrication as possible of all the systems of the building. The OPEN_1 House uses universal design principles and includes an elevator, pull down cabinets, accessible height counter-tops and tables, and accessible doorways and bathrooms.

Site: The OPEN_1 House prototype residential unit is constructed on a sloped site using a concrete basement foundation. A concrete basement foundation is not compatible with whole building disassembly as a buried and relatively inaccessible assembly. It can have benefits however in the exposure of, or access to, mechanical, electrical and plumbing systems (MEP) for the floor above and at the entrance point to the building.

Structure: The structure of the OPEN_1 House is based on the use of pre-fabricated wood-framed panels with sheathing and finishes within a timber-frame support. These panels are built in modular units, with

Fig. 33 exploded axonometric view of OPEN_1 House

dense pack cellulose insulation and all sheathing applied in the factory, and final building assembly on site. The building exterior is designed on a grid system which also integrates the interior elements. The first floor is constructed using open web steel trusses, and upper floors use the Open Built™ Spacer which creates a plenum between floor structure and ceiling below to allow for ductwork and other utilities to run uninterrupted. The roof system uses a structural insulated panel (SIP) system, which is pre-fabricated and could be cut into panels if disassembled.

Skin: Windows are designed with installation details that permit relatively easy removal and replacement without requiring the destruction of the surrounding framing. The windows are installed using self-adhering flashing elements that in turn are trimmed out with removable pieces. The wall panels are furred out with a 2" furring element that allows wiring to be run vertically and horizontally beside the wall framing rather than entangling them within the cavity or requiring holes to be cut in the framing members.

Services: An open raceway is built into the base of the interior walls and is accessible by a removable cover. This allows the placement of wiring without either entangling them in the wall cavity or having to expose them. All plumbing is consolidated into specific zones of the house. The floor plenum system contains all ductwork and other utilities and is concealed by pre-manufactured modular ceiling panels laid into an exposed wood frame. These ceiling panels operate like a commercial office suspended ceiling grid tile system.

Space Plan: Design for adaptability / disassembly features of the OPEN_1 House are highly compatible with the universal design requirement dictated by the building program. The Open-Built™ Floor system ceiling panels provide a unique feature of allowing an owner to change the ceiling finish of the house without disrupting any other element, as long as the grid dimensions are maintained for any new lay-in finish. Because the ductwork and wiring are not intertwined with other assemblies, they can be altered along with any new space configuration.

Fig. 34 preassembly of an interior wall

Fig. 35 ceiling panels

Fig. 36 typical Bensonwood heavy timber framing

- ***R 128 House***

The R 128 house has an explicit mission to be dismantleable and to allow for all its materials to be either reused or recycled. It is also unique for its use of pre-fabrication and highly modular systems for a site-specific project. This is an example of so-called mass customization. Basic considerations include off-site pre-fabrication to increase efficiency, eliminating permanent joining methods that form composite components that may be difficult to recycle, and eliminating mechanical and plumbing systems that are covered over by plaster and drywall or buried in concrete.

Site: The building is built upon the same footprint of a pre-existing building that was demolished to make way for the new building. The slope of the site requires a terrace-style foundation, and there is no basement or use of deep excavation.

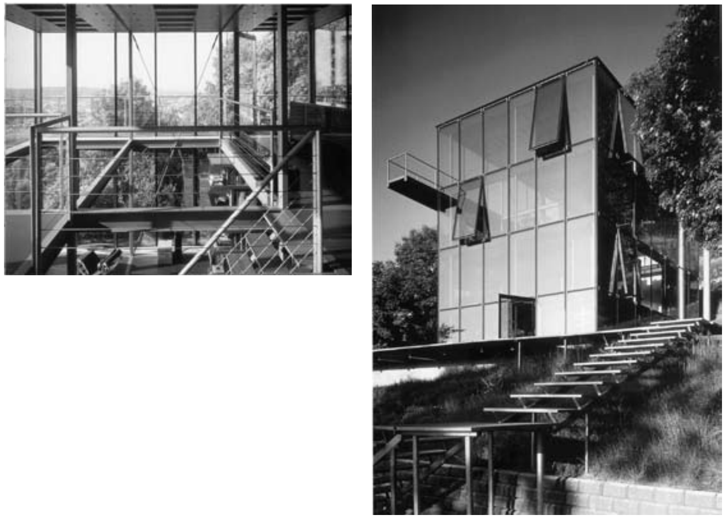


Fig. 37 R 128 House, interior and facade

Structure: The structure is an exposed steel frame to minimize mass and maximize efficiency of construction and connections. The bolted steel frame can be un-bolted for disassembly. The open steel frame is braced diagonally on three sides by tension rods. Columns and beams are connected using bolts that use threaded holes in the columns.

Skin: The house form is a cube, both to maximize structural and materials efficiency but also to maximize energy efficiency in a cold Northern Europe climate with an efficient volume-to-surface area. The envelope is comprised of gas-filled sealed triple-glazed glass panels and operable windows, with temperature modification provided by a water-based heat exchange system circulating in the ceiling.

Services: The lighting and doors are controlled by both remote and voice activated controls. All pipes and other utilities are placed on vertical and horizontal chases or channels. The bathrooms are comprised of pre-fabricated modules inserted into the building. Controls for many electrical and plumbing systems are managed by motion or voice controls in lieu of traditional switches.

Space Plan: The steel frame is articulated within the interior of the building facade with attention to the connection details. The floors are a series of panels placed by gravity into channels between the floor structural beams without use of nails or screws. The ceilings are made from metal panels that are clipped into place.

Fig. 38 Intelligent Workplace interior and structure

The Intelligent Workplace design employed nine modules, differing only in width. The design was also driven in part by the characteristics of major components donated by building industries. The Mahle flooring system, for instance, uses a 600mm module that helped to establish the dimensions of the massing modules. The curtain wall is a variant of the Gartner product line. It is related to the curtain wall of Gartner's own corporate headquarters in Gundelfingen, Germany (1988-1992).

http://www.library.cmu.edu/Research/ArchArch/ACampusRenewed/IW.html

Fig. 39 entrance

Fig. 40 connection detail

Fig. 41 raised access floor panels

Fig. 42 exterior louvers

Institutional

• *Intelligent Workplace at Carnegie Mellon University*

The Intelligent Workplace (IW) was designed as a vertical addition to the Margaret Morrison Building on the Carnegie Mellon University campus. The IW serves as both office space and a living laboratory for open office and sustainable building systems research and development.

Site: By utilizing an existing building footprint, the IW has minimal impact on the natural surrounding site. Due to its DfD attributes, the impact on its host building is also limited and reversible. This building is a good example of future building opportunities in densely populated urban areas.

Structure: The structure is composed of pre-fabricated 100% recycled steel open-web trusses that span the entire width of the building. At the ends, these main trusses are supported by column units that then provide an entirely open interior space plan. As this structure was built on the footprint of the building below it, the assembly required a pre-planned and pre-fabricated approach to reduce complexity. The basic structure took four days to bolt together. The open web trusses allow spaces for the running of mechanical ducts and other utilities within the depth of the truss. The roof uses a metal decking system, the underside is the exposed ceiling of the space below.

Skin: The building envelope components are prefabricated and modular to reduce on-site waste and aid in adaptability. The predominant envelope material is high-performance glazing. Large windows completely surround the building and full-length glass doors open onto an outdoor terrace that wraps around the facility. Facing the terrace, a series of photovoltaic light redirection louvers control day-lighting levels while generating DC power. The roof is clad with insulated roof panels and features a series of skylights.

Services: By employing a raised-access flooring system and open web trusses, all the utilities are able to be run either through the floor or overhead. A raised-accessed floor creates its own air plenum thereby eliminating distribution duct-work. Due to the lack of wiring in interior walls, this strategy enables a flexible space plan as well as allowing for easy access for repair and renovation. Having the services clearly visible also makes it easier to visualize and perform disassembly.

Space Plan: Flexibility and mobility are two guiding factors in the interior systems. To accommodate the ever-changing needs of classrooms, offices, meeting spaces and laboratory areas, most of the interior partitioning is composed of modular, stackable and/or mobile components. Office spaces are delineated with the use of cubicles in single, double and quad arrangements.

- ***California College of the Arts (CCA)***

In 1951, Skidmore Owens and Merrill (SOM) designed the 60,000 square foot industrial structure that now hosts the CCA. By maximizing the reuse potential of the original structure, the architects, Tanner Leddy Maytum Stacy, were able to create a healthy sustainable environment exemplifying design for reuse and disassembly.

Site: The CCA is located in the urban heart of San Francisco and utilizes an existing building to house its program. The prior use of the building was a bus maintenance facility, which resulted in large deposits of hazardous materials on the building slab. These hazardous materials were isolated by pouring a new slab on top of the existing slab. This does not exemplify the DfD concept of eliminating toxicity from the built environment, but rather illustrates a mitigation technique to allow the reuse of an entire building rather than forcing the demolition of the structure.

Structure: The original SOM design used a three-hinged frame with finger-jointed knee systems for a large open span, suited to maneuvering city transit buses within the space. Even though these members maintained their structural stability, current building codes for seismic bracing required the introduction of additional steel elements from the floor to the frame. However, a basic open structural grid is maintained.

Skin: Three sides of the exterior consist of 30-foot high, single-glazed curtain walls, which in conjunc-

Fig. 43 utility raceways

Fig. 44 exterior glazing

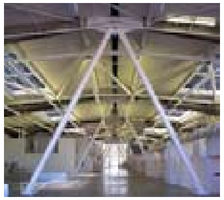


Fig. 45 new structural members

Fig. 47 The 1951 SOM bus maintenance facility required seismic bracing, toxic soils remediation, and other treatments. Photo: Richard Barnes

Fig. 46 mobile studio partitions

tion with the open floor plan allows for an abundance of daylight within the interior workspaces. Even though the structure is 60,000 square feet, in Northern California heat gain is not an issue as it would be in warmer climates for a similarly glazed building. The roof also contains large skylights for additional day-lighting.

Services: The use of passive systems (day-lighting) greatly reduces the amount of artificial lighting required. Approximately 70% of the renovated space is solar-heated via 49 flat-plate collectors that feed into a 15,000 gallon water storage tank. The heated water is then circulated through hydronic coils in the same concrete floor that is separating the interior environment from the historic hazardous materials contamination. Due to the high roofs and flexible partition system, electrical and communications cabling is run in exposed cable trays mounted independently of the moveable partition walls. These trays are arranged in the form of a semi-permanent infrastructure in simple patterns to accommodate current or future cabling.

Space Plan: Large open studios are formed by mobile partition walls supported by castors that can be lowered or raised to set the base of the wall on the floor or move it. The craft shop section of the school is located in permanent acoustically separated spaces along the eastern long side of the building. These interior walls are constructed of recycled-content and recyclable light steel framing.

Fig. 48 IKEA facade

Fig. 49 structural connection

Commercial

• *IKEA*

IKEA is a well-known home products retailer, devoted to environmental responsibility while "offering a wide range of well-designed, functional home furnishings at prices so low that as many people as possible will be able to afford them" (IKEA, 2006). Physically, these stores are representative of the "Big Box" building typology. The large-scale open warehouse building has survived in many urban settings for its inherent adaptability. How well the modern variants in Greenfield locations will actually be adapted versus demolished, may not be fully tested. IKEA provides a good example for DfD both via its retail facilities and its home furnishing products.

Site: One of IKEA's distinctions from other big-box retailers is the common use of a second floor, thereby more effectively using the building footprint.

Structure: The basic structure of the IKEA facility is a steel column and open-web truss system with a slab-on-grade foundation. As a material, steel is 100% recyclable and the Steel Recycling Institute claims an industry average of 67% recycled-content for the US. The unfinished interiors expose all the structural members and their connections making it accessible for deconstruction both visually and physically.

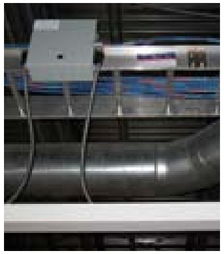


Fig. 50 electrical and telecom raceways

Fig. 51 ceiling grid and partial height display walls

Skin: IKEA stores are typically clad in corrugated steel and use skylights for ambient lighting throught the building. The inherent separation between structure and skin in a post and beam system allows for the variations in building skins between large expanses of glazing, to metal, to infill using concrete masonry units.

Systems: The large display spaces are organized by a series of partial height walls. These partitions can be readily removed without any interference with each other. In lieu of any ceiling finishes, a large suspended metal grid with u-shaped channels is used to run electrical wiring and mount lighting at specific locations. This suspended grid creates a ceiling plane, supports all lighting and also provides support for the wiring on the top side. The Pittsburgh IKEA has also incorporated photovoltaic arrays into their building. Although not always recognized as a DfD aspect, photovoltaics do have the potential to reduce the connections to point source electrical distribution through distributed systems, thereby increasing the modularity of the building's electrical systems.

Space Plan: The interior wall panels of the IKEA store in Toronto are manufactured by Faay Vianen and made from flax waste and plaster board. Flax is a rapidly renewable material and the solid panels are glued at the seams with a soft-point glue that can be cut to separate the panels for flexibility or re-arrangement. All stores have on-site recycling collection and a facility in Sweden has an on-site recycling facility.

- ***Wal-Mart Eco-Store***

The first of a series, the Wal-Mart Eco-Store in Lawrence, KA was designed by William McDonough + Partners and built in 1993. Beyond other basic green building attributes, the store was also designed to be a response to the potential obsolescence of the store as a single-use design. In lieu of demolition, the building was designed to be convertable from a retail store to housing. This building also had a considerable focus on materials selection including wood from sustainably harvested sources.

Site: Although the building is one-story in its first use, it is designed to be a two story building in its future conversion thereby using land more efficiently. The parking lot makes use of recycled concrete aggregate (RCA) from the demolition of a pre-existing structure. Approximately 54 of 60 pre-existing trees were reclaimed and relocated, and an on-site storm water retention pond is used to supply irrigation water.

Structure: In lieu of very deep (6') open-web steel trusses to span the large bay sizes common for an open floor plan retail space, large laminated wood trusses of much less depth were used and the underside of the roof envelope was designed to be the ceiling appropriate for the future residential use. By not using deep trusses a sufficient floor-to-ceiling height was able to be maintained without the trusses interfering. The height of the building was raised an additional 3' over the norm for a high-ceilinged one-story space, to accommodate the insertion of a second floor within the vertical height of the existing building.

Skin: The concrete block walls of the building envelope were laid out in courses of modular increments to allow for pre-planned patterns of openings to be created for additional doors and windows by removing whole blocks rather than cutting and demolishing.

Systems: Extensive prismatic skylights were used in the building to light the current retail space, but that in the future would also be used to daylight the second floor residential units. HVAC systems utilized HFC 134a, rather than more ozone depleting CFC-based refrigerants, which would also then require potentially more expensive disposal methods at end-of-life.

Space Plan: The building is one-story, but in order to convert to residential use, the ceiling height was raised by three feet to allow for a second floor to be inserted into the existing height of the building.

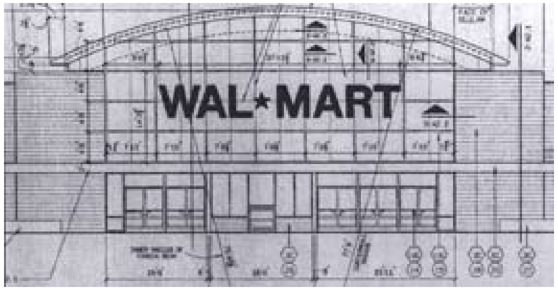


Fig. 52 “eco-mart” design drawing

Fig. 53 finished facade

Fig. 54 Herman Miller SQA complex

Industrial

• *Herman Miller SQA*

The 290,000-square-foot Miller SQA building was designed by McDonough + Partners to be a state-of-the art “green” building. The building is a combination of manufacturing plant, warehouse, and headquarters. A long glass-roofed atrium “street” was designed as an interstitial “public” space that both mediates and connects the office and manufacturing areas.

Site: As a part of the construction process, the surrounding site was reclaimed as prairie wetlands using native plants, and passive landscaping techniques. Flexibility for the facility’s operations was created by placing loading docks on three sides of the building. This allows for adjustments to be made to the interior manufacturing processing layouts with multiple access points to the exterior, in an efficient manner.

Structure: The structural system for the building’s roof is comprised of open-web vaulted trusses allowing for the integration of numerous skylights that in turn provide extensive day-lighting for the manufacturing space. The steel frame structure using bolted connections and a highly recyclable material is highly compatible with DfD. In the case of steel, a recycling process does not depend upon maintaining the integrity of each individual element. The material’s qualities of recyclability could substitute for the need for bolted connections, but bolted connections provide for the opportunity for reuse, which is preferable than recycling.

Skin: The building includes approximately 47,000 sq ft of glazing providing maximum day-lighting for the facility. Low-e glass was utilized for all glazing for high-performance day-lighting while minimizing energy losses. The external brick sheathing is manufactured locally. As a modular and pre-manufactured building material, brick has potential for disassembly as long as the mortar is not stronger than the brick and highly adhered to the brick - as is the case with modern cementitous mortars. Hydraulic lime mortars can overcome this problem. Selecting local materials can have the impact of insuring future reuse and recycling due to the fact that transportation distances and compatibility of material inputs to a remanufacturing or recycling process are critical factors to the economics of both reuse and recycling. The likelihood of developing a reuse and recycling market will be greater based on the original producer's proximity to the building site.

Services: Radiant floor heating systems are built into the office area exterior walls, substituting for forced-air systems and eliminating separate duct networks. This system uses convection to circulate conditioned air from the lower level to higher levels through the space with minimal energy inputs. Embedding these utilities into any wall is not optimal for DfD but using the exterior walls is commensurate with the notion that Skin is longer-lived and less apt to be changed than Space Plan, i.e. interior partitioning and finish systems. The building's artificial lighting system uses a passive infrared motion sensor and internal clock so that the appropriate amount of light is chosen for the time of day. The combination of day-lighting and sophisticated controls minimizes the requirement for additional lighting services infrastructure.

Space Plan: The atrium "street" is used as the major space-defining element between the manufacturing space and the office wing. This has the affect of creating 'two' buildings connected only by a light-framed and predominantly glazed interstitial zone. This in turn allows for spatial flexibility at the scale of the whole building. Material selection for all interior building materials, was based upon issues such as embodied energy, toxicity, volatile organic compounds (VOC) content, durability, and recyclability.

Fig. 55 production floor

Fig. 56 the "street"

Components & Materials

As outlined in earlier sections, there are basic principles that form the foundation of the Design for Disassembly process. This section will focus on materials that give shape to these practices. Without utilization of the appropriate materials, there would be no benefits to designing in such a manner other than the ease of removal and adaptability. The essential overarching goal of DfD is to not just to ease the recovery process, but to ultimately facilitate a zero-waste and closed-loop materials flow system for the built environment. Thus, it could be said that the success of the DfD concept will be dependent upon the choice of materials, starting with materials that are reused or from recycled-content. Inherently, all materials will have pros and cons, but the following review of materials and products will reveal some considerations by example.

When employing DfD, one must first recognize that materials have both upstream and downstream impacts, depending upon pathways from origin, and then after the initial building installation and use phase. At the end of a material's first life, one of multiple scenarios can take place. As the materials cycle through these scenarios, they will inevitably degrade and fall into other categories. In the end, the ideal material is one that can be reused multiple times, maintain acceptable quality and be recycled (as in McDonough's cradle-to-cradle scenario), burned (instituted energy recovery) or decomposed (a natural recovery process) with little to no harmful off-gassing.

Materials Qualities to Enhance DfD

Flexibility within a material type is very helpful in dealing with renovation and reuse. This refers to both physical flexibility as well as its ability to serve multiple needs and adapt to different users. The simplest example is 1x wood materials, which have many uses, and can be combined to create deep members with greater strength.

Minimize the amount of material used. Using fewer elements makes the structure easier to understand, deconstruct, move, etc. Modularity allows for discrete components that can be mofied without impinging on other parts. This can also reduce the amount of overall waste produced during construction and deconstruction.

Replace active service elements with passive elements to reduce amounts of additional materials and mechanical servicing in a building and hence easing deconstruction. Examples include double-skin facades and day-lighting design to reduce requirements for mechanical air-conditioning and electrical lighting, respectively.

Fig. 57 wood

Fig. 58 metal

Fig. 59 concrete

Fig. 60 masonry

Avoid the use of adhesives, resins and coatings. Use of these items can lead to unnecessary destruction and premature discarding of materials.

Anticipate differential wear and tear such as with finish floors, wall corners, and door hardware in comparison to than their accompanying sub-components of sub-floor, wall surface and door, respectively. Anticipating this differential wear will mean making finish floor float apart from the sub-floor or easily separable; corners of walls made from a discrete, detachable more durable material than would be necessary on the face of the wall; and affixing door handles with accessible connectors for ease of removal without affecting the body of the door.

Specify limited sizes for elements, beams, trusses, wall members, etc. as this can facilitate the ease of their eventual reuse, handling and design for reuse (Webster, 2006). If using limited variations and common dimensions it is vital that the connections do not compromise the integrity of the members at the point of connection. Avoid connections that will require cutting or resizing in order to recover and handle individual elements.

Site, Structure, Skin, Services, Space Plan, Stuff

Chosen for a multitude of reasons, the following sampling of components and materials possess various characteristics that aid in Design for Disassembly. The categories of ***Site, Structure, Skin, Services, Space Plan*** and ***Stuff*** are used to categorize the components although many materials could be used in several categories.

Site_ As the element that will remain after the life of any structure has ended, it is important that the impacts of a building relative to a site do not alter it negatively in perpetuity. Design the building project to have a very light impact on the site that is easily reversible.

Native & adapted plant species

- Landscape using native and adapted species that do not require irrigation, fertilizers, or pesticides. By eliminating irrigation systems, there is less entanglement of sub-surface plumbing systems with other landscape elements or infrastructure.

Principles: *eliminate / minimize toxicity, durability and low maintenance.*

Unit pavers

- Unit pavers provide for adaptable and reusable hard surfacing systems. Optimal materials include reclaimed brick and stone, and then products with recycled-content.

Principles: *reusability, modularity, simple and accessible connections, mechanical in lieu of chemical or bonded connections.*

Low impact foundation technology (L.I.F.T.)

- LIFT systems use steel pipes to anchor foundation walls or piers into the bearing soils. If used with bearing walls, the concrete wall acts like a beam that spans from one collar head to the next, and the two bearing pins at each head collar transfer the load to the bearing soils. When used with piers, the pins are angled in opposing directions to anchor the pier. A buffering material separates the base of the stem wall from the surface soils, so that any potential frost or expansive heave is not transferred

to the wall or pier. These systems do not require extensive trenching and facilitate the removal of the concrete wall or piers at building end-of-life.
Principles: *accessible connections, simple and disentangled connections, modularity (piers), reusable and recyclable materials.*

Fig. 61 L.I.F.T.

Structure_ The structure is the longest lasting, and hence least flexible, of the major building assemblies. Because of this, durability of the materials is a critical consideration, along with disentanglement from systems with different functions and life-cycles. Structural connections and assembly/disassembly should be evident through observation as much as possible, or be easily accessible. As the structure can make up a large portion of the mass of materials used in a building, large environmental impacts can be mitigated through the reuse and recycling of this category of materials. If intended for recycling then they should not be contaminated by other materials, or if coatings, etc. are essential, then the system should be designed with economic and available separation processes in mind.

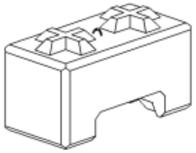


Fig. 62 modular block gutter

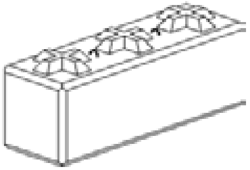


Fig. 63 modular block 3 Cross

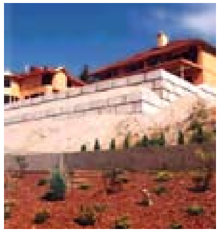


Fig. 64 retention wall

Modular block retaining wall systems

- Modular block, or segmental, retaining walls employ dry-stack interlocking concrete units that use gravity and the naturally occurring lateral forces to resist loads. These pre-engineered modular systems are inherently flexible and accommodate a wide variety of site constraints conditions. The absence of mortars and additional reinforcing means that they are readily demountable and reusable.

Principles: *homogenous materials, reusability, modularity, simple and accessible connections, mechanical in lieu of chemical or bonded connections.*

Concrete

- Pre-fabricated concrete columns, beams, and planks have the potential for reuse based on theh connections and avoidance of poured in place topping slabs over floor systems. Connections made from stainless steel and removable fasteners will be both durable and allow disassembly. Concrete is highly durable and can be formed in modular units for flexibility. There is a robust infrastructure for concrete recycling in the U.S. and steel reinforcing is readily separated and recycled as part of the process.

The majority of concrete components (sand, rock, water) come from non-toxic and readily available materials, although the production of cement is energy-intensive and can result in a high rate of green house gas emissions.
Principles: *high recyclable, durable, modularity.*

Light-weight concrete

- Autoclave aerated concrete (AAC) is a lightweight concrete made from sand, lime, cement and water, and alumina, which is added as an expanding agent. After the materials are mixed to form a slurry, it is poured into a metal mold. The alumina reacts with the other materials to form small, finely dispersed air spaces in the material. After curing, the molds are cut and the pieces are then steam-cured in an autoclave. AAC can be used to make blocks and panels, and reinforcing can be added into the molds before the slurry is poured. The resulting products are a low density concrete combining structural strength and insulation in one material. With an average cured weight of under 50 lbs per cubic foot (compared to 150 lbs per cubic feet for concrete), pumice-crete and AAC produce a cured strength of 400 psi (compared to 2,000 psi in concrete) with an insulating value of R-1.5 per inch (compared to R-0.1 in concrete).

Principles: *dematerialization, multi-functional materials, recyclable, non-toxic (pumice).*

Structural insulated panels (SIPS)

- Pre-fabricated SIPS combine sheathing, structure and insulation into one relatively lightweight building component. A typical SIP is comprised of a core of rigid insulation, bonded to two layers of oriented strand board to make the panel. The panels are typically built in 4’widths and up to 20’ lengths in 4’ increments. The main obstacle to the disassembly of SIPs is the use of construction adhesives to connect the bottom spline directly to a wood sub-floor or to a sill plate that is bolted to a concrete slab system. The panel can be removed by either cutting behind the wood spline and re-routing a new spline, or by cutting at the seam between the spline and the wood sill or top plate. The use of splines that act as separate connectors allow for the spline to be removed to release the connection between panels.

Each panel should remain an integral and structural unit even if cut into slightly small panels. For example, if the original panels are 9’ in height, cutting 6” off of top and bottom would still produce 8’ tall panels for a second use. SIPs are a composite, which inhibits recycling as individual materials, however the substitution of wheat-straw for expanded polystyrene (EPS) as the infill material has potential for less environmental impacts from manufacture and greater potential for recycling and biodegradation.
Principles: *pre-fabrication, modularity, reusable and recyclable materials.*

Fig. 65 SIPS

Reclaimed lumber

- As long as it has not been contaminated with toxic preservatives, paints, or adhesives, wood can be reused, recycled, bio-degraded or burned for utilization of its energy content. Solid lumber of sufficient dimension is a highly flexible material for reuse and remanufacturing, as it can be cut and worked to make new sizes and shapes without loss of its base properties. Light wood-framing, while an efficient use of lumber, is problematic for disassembly often due to the use of a large number of nails and many small increments of material of relatively small dimension. Clips, angles and plates, bolts, double-headed nails, are means to make the wood members easier to disassemble. As tools to more rapidly remove nails is developed the labor intensity of disassembly will become less. Building light frame wall panels allows for the potential for the recovery of entire panels for reuse in their entirety as a panel unit, maintaining higher value. Timber framing is typically preferred as it maintains larger sizes of members and typically uses fewer, larger connections.

Principles: *precautionary principle, reused material, reusable and recyclable material, non-toxic and homogeneous materials.*

Engineered lumber

- Engineered lumber products provide an advantage over solid wood by utilizing fast-growing, small diameter trees in efficient manufacturing processes. As an engineered product, the material uses minimal materials while maintaining a high degree of quality and strength characteristics. Engineered materials are problematic for recycling because of the use of adhesives and binders, although tests are being conducted to ascertain the environmental impacts of these materials as mulch products. The use of these resins also has implications for human and environmental health from their manufacture. The advantages of engineered products lies in their resource utilization and their high tolerances which can create more certainty for reuse as structural materials.

Principles: *standardized dimensions, dematerialization, reusable.*

Open-web steel joists

- Open-web steel joists are lightweight, high-strength framing members that can provide long clear spans, which allows for more open floor plans and adjustable spaces. The use of an open web allows for the depth of the member to be used for mechanical and other utilities with minimal entanglement. The steel industry claims an average 85% industry-wide recycling rate, which hot-rolled steel exceeding 90% recycled content Metals are completely recyclable as long as it can be economically separated from composite systems and adjacent materials in the building dismantling and materials processing stages. Connections of steel members and steel to other materials such as concrete can be accomplished using bolts for the purposes of reuse and welds or bolts for purposes of recycling.

Principles: *recycled and recyclable, reuseable, long-span,*

Fig. 66 engineered lumber

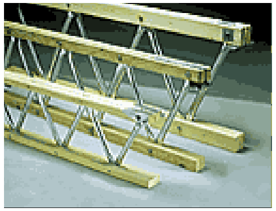


Fig. 67 metal-web wood

durability, disentanglement.

Screws, bolts and connectors

- Screws, bolts and other forms of dry connections allow for ease of disassembly as opposed to friction nails or adhesives. Where nails or bolts are used with connectors, this may allow for fewer nails and therefore less damage to wood members. Various companies have developed specialized connectors for specific applications. For example, one company has developed a line of connectors for decking that allows for connectors accessed from the back side of the materials and that provides potential to use butt-jointed materials with little to no penetration of the decking materials by any connectors.

Principles: *accessible connections, standard and fewer connections, reusable, recyclable.*

Stone

- Like brick, when used with a lime-based mortar or dry-stacked, stone can be readily designed for disassembly Stone in proper uses is highly durable and reusable, and when used in modular sizes is readily repairable. Stone's major drawback is the high degree of labor and equipment to construct.

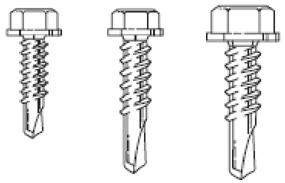


Fig. 68 steel decking screw

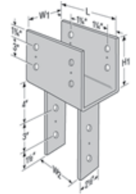


Fig. 69 column cap

Fig. 70 rafter connector

Skin_ The building skin (walls and roof) bears the brunt of weathering forces. It is required to provide durability and impermeability to external moisture and temperature, but at the same time allow access, light, and controlled air and moisture exchanges between interior and exterior environments. The combination of barrier, filter or total porosity creates potential conflicts between repair and replacement of finish materials and sub-components such as windows, doors, vents, chimneys, each with varying short life-spans. While durability and building energy-efficiency are the most desirable operational characteristics for building skins, adaptation and whole-building disassembly dictate use of materials that can also be reused and recyclable

Metal roofing

- Metal roofing is highly amenable to deconstruction. It is sheet material of light-weight per unit of area and is typically mechanically fastened. The various alloy roofing types can be recycled or reused, although reuse is problematic given the penetrations caused by the connecting screws. The use of screws allows for relatively efficient disassembly using simple tools and low-skill labor.

Principles: *accessible connections, recycled and recyclable material, modularity,and ease of handling.*

Mechanically fastened ethylene propylene diene terpolymer (EPDM) single-ply roofing

- Mechanically fastened EPDM single-ply roofing and insulation systems can allow for ease of disassembly within the constraints of code requirements and weather conditions per the site location. Mechanically fastened single-ply roofing can be

applied over multiple roof decking materials. Ballasted systems have the advantage of using passive weight of the ballast in lieu of fasteners, but the ballast is heavy and labor intensive to remove. Research is currently underway to develop recycling systems for this material.
Principles: *simple accessible mechanical connection, dematerialization.*

Wood siding

• Wood as siding can be good material for DfD in particular when used in a vertical application which allows for the replacement of individual boards without impinging upon adjacent boards. Horizontal lapped siding is limited by the layering which laps each piece above the piece below. However, a horizontal pattern means that, while the lower pieces are most susceptible to wear via splash back and in turn rotting, this decay will be limited to the length of fewer pieces rather than the ends of every piece in a vertical application. Painting wood siding greatly limits its reuse and recycling potential while increasing its life. This is a trade-off that can be somewhat avoided by design which allows for deep overhangs and rain-screens or other drying wall designs that prevent the accumulation of moisture.
Principles: *reusable and recyclable materials, modularity, mechanical fastening, light-weight and dimensional regularity.*

Brick with lime mortar

• Clay brick is a highly durable, and an easily reusable material if used in combination with a lime mortar. Reused brick material is optimal when compared to new brick, although reuse of brick for structural purposes can be problematic. Absorption of existing mortar will inhibit a good bond for new mortar and freeze–thaw action will weaken exterior brick over time.
Principles: *modularity, reusability.*

Mortar-less brick veneer

• Mortar-less brick veneers are designed with a profile similar to novelty wood siding and employ a “dry” connection (screws) in lieu of a “wet” system of mortar for bonding. Installers stack the blocks in rows, from the bottom up and lap each course, then screw each unit to vertical furring strips attached to the wall sheathing. The furring strips provide a positive connection and create an air space, allowing the veneer surface to breath and providing drainage for any moisture that may penetrate. This system uses a highly specific brick shape that limits its reuse options compared to a solid brick, but allows for ease of disassembly using less effort compared to the use of mortars and wall-ties with standard brick veneer.
Principles: *screwed mechanical fasteners using fewer and simple tools.*

Exterior windows & doors

• The energy-efficiency, weather-proofing, and durability characteristics of the window units typically take precedence over the environmental impacts of the materials of construction. Residential units and many commercial door and window systems are pre-fabricated and designed for ease of “dry” installation and possible removal. However, this ease of removal can be compromised by flashing and exterior finishes that overlie the window flanges and prevent ease of removal without damaging the adjacent finish materials. Methods have been developed to create an exterior weather flange over an inner flange that is placed to the inside of the wall, allowing for removal of the window to the inside after removal of the exterior flange. With detailing to allow for removal to the interior, windows and doors are highly reusable as components.

Principles: *pre-fabrication, modular and standardized dimensions, self-supporting and interchangeability.*

Light-gauge metal framing

- Light-weight steel framing is an alternative to conventional light wood-framing for structural and non-structural assemblies. Light gauge steel is lighter, stronger, and moisture and insect-resistant when compared to comparable light-wood framing. If screwed together, steel members can be disconnected more readily than wood-members and the homogeneity of the framing and connectors also allows it to be recycled without disconnecting the individual framing members. Pre-punched knock-outs allow for running electrical wires between members without additional cutting, drilling, etc.

Principles: *recycled and recyclable, durable, non-toxic, disentanglement.*

Loose insulations

- Cotton, cellulose, fiberglass, and mineral (slag or rock) wool batt or blown-in insulation can be readily removed in a disassembly process and reused because they are not adhered to the structure or envelope. In the case of horizontal planes such as floors or ceilings, the products can be suspended or set using gravity. The trade-off is that they do not act as sealants such as with wet-applied and expanding insulation products, although dense packed cellulose mitigates some of this shortcoming. Fiberglass is problematic due to its fibers as a potential health issue, but all of these forms of insulation can be recycled and are made from recycled-content, except rock wool. Slag wool is made from blast furnace slag, while rock wool is made from natural rock material (Green Sage, 2006).

Fig. 71 mortarless brick

Fig. 72 exterior doors and windows

Fig. 73 light-gauge metal framing

Rigid insulation

- Rigid foam insulation such as polyisocyanurate (polyiso), expanded polystyrene (EPS) and extruded polystyrene (XPS), popularly known under its trademark name Styrofoam, are cut into panels and fitted into walls, floors and ceilings. They are also used externally on decking, under roofing or over wall sheathing under the exterior siding. When removing the panels in a disassembly process their self-supporting form will allow them to be removed intact for reuse. These materials are also recyclable and can be made from recycled-content. A major distinction is that EPS uses pentane as a blowing agent whereas polyisocyanurate and XPS use variants of ozone depleting chemicals.

Principles: *minimal connections, reusable or recyclable materials, low-skill and equipment applications.*

Services_ In traditional construction, duct, wiring and pipe is often attached in destructive ways to other elements through holes in members, welds, clips, clamps, etc. Entangling piping and wiring within wall, floor and ceiling cavities also makes it difficult to access for repairs without also damaging overlying elements. During disassembly, these elements often require extensive effort to un-thread and un-attach them from the other building elements. Thus, how the services are integrated into a building can either greatly impede the disassembly process or at minimum allow for easier repair and ultimate disassembly.

Plug and play electrical systems

- Plug and play electrical systems are driven by modularity and interconnectivity protocols that allow for interchangeability. Plug-and-play implies that a unit can be placed at any point on the electrical system without re-engineering the controls and the entire system. A simple example of plug and play is the use of standard plugs for electrical appliances, whereby the modular component is the plug. Any appliance can be connected via a common plug system and any plug can be interchanged with another. As these systems become more developed they will allow for ease of connection for larger space-conditioning equipment, photovoltaic systems, etc. These systems will also be able to be used in the power distribution for a residence, for example, where the wiring can be easily disconnected on a room by room or zone by zone basis without impinging upon the whole system or require capping, pulling or disconnecting an entire run.

Principles: *reusable, modular, ease of access to connections, simple connections, ease of logistics.*

Electrical raceways

- By creating a small cavity along the baseboard of a wall, with a clip-on baseboard cover, the residential raceway systems developed by Bensonwood Homes allow for electrical distribution wiring to be hidden while remaining readily accessible. Generic ceiling raceways, both exposed, or hidden by suspended ceiling systems, are commonly used in commercial, institutional and industrial buildings. These overhead raceways must be suspended in tracks.

Principles: *reusable, modular, ease of access to connections, simple connections, ease of logistics.*

Fabric air dispersion systems

- Fabric air dispersion systems utilize a lightweight material with controlled porosity to distribute air while it also filters through the duct material at the same time. The material is flexible, eliminating bends and connections, and its tubular structure is created pneumatically by the air pressure through the duct material. The duct tubes are suspended from lightweight hangers snapped on to a tensioned

Fig. 74 electrical raceways

Fig. 75 fabric air dispersion systems

cable and the fabric in turn is clipped to the hangers, without use of specialized tools. The process of removal entails simply unclipping the fabric.

Principles: *minimize and simplify connections.*

Wireless sensors and control systems

- Wireless systems for monitoring, controls and communications are becoming increasingly common. Wireless systems have the benefit of reducing wiring altogether in buildings. Since the sensors and transmitters do not have wiring to begin with, the system components can be relocated freely without any new wiring or interference with other systems in the building. The advantages of wireless systems include less entanglement of service systems, less damage to other components from attachment systems and an increase in speed of the disassembly process. Wireless systems also have potential for storing information about the building and its components through reading radio frequency identification (RFID) tags and other sensors.

Principles: *document building information, separation of MEP systems, interchangeability.*

Flat wire systems

- Flat wire products basically flatten traditional round wire or cable into extremely thin profiles, approximately the thickness of a card stock paper. These products are then laid directly over a finish substrate rather than within a cavity, as they do not require any appreciable depth. The wire is adhered and then can either be left exposed or covered by a tape similar to drywall joint tape and painted over. This product has several implications for DfD – by placing on the surface of walls and floors it eliminates entanglement in wall and floor cavities, as an adaptation method it prevents unnecessary demolition of walls and ceilings for application, while as an adhered product, it may be difficult to separate for recycling using hand methods. This can be weighed against the value of allowing for ease of recovery of the cavity wall or floor structure assemblies and maintaining their integrity.

Principles: *accessibility, dis-entanglement.*

Cross-linked polyethylene (PEX)

- PEX can be used for any interior application where plumbing pipe would be used. It is flexible material, making it easy to install and bend. The flexibility means fewer joints and hence less fittings and labor. PEX uses mechanical connections such as heavy duty acetal compression fittings that attach to the outside of the tubing pipe and use a simple wrench to tighten. As a relatively new product, its long-term performance and any human health impacts associated with its use for potable water delivery are not completely known. The precautionary principle may apply to its use and it is highlighted for the physical performance and assembly / disassembly properties only.

Principles: *simple homogeneous materials, avoidance of chemical connections, use of simple friction fittings.*

Manifold plumbing systems

- PEX can be used with manifold or home run plumbing systems that are much like a breaker box for the electrical system. The manifold provides a common location from which all the plumbing fixtures are supplied. Some manifolds also feature fix-

ture shut-off valves allowing the user to shut off the water to individual fixtures from one location. Others are semi-home run manifolds or termination manifolds, which may feed the plumbing requirements for a room or set of rooms and reduce the number of fittings required in the plumbing system.
Principles: *accessible connections, interchangeability.*

Waterless urinals

- Waterless urinals do not use a water supply for flushing thereby reducing the use and entanglement of these elements. While they still require a drain line, the reduction in piping compared to traditional water-flush systems reduces the piping complexity and requirements for disassembly of these components in an adaptation or whole-building disassembly.

Principles: *simplicity of connections, minimizing connections.*


Fig. 76 Flat wire

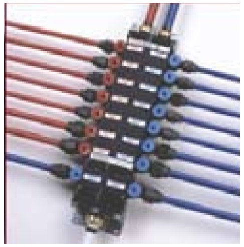


Fig. 77 manifold plumbing


Fig. 78 waterless urinal

Space Plan_ The space plan elements can involve interior structural and non-structural elements, mechanical, electrical and plumbing systems entanglement, the sub-division of space and flooring systems that will inevitably experience considerable wear over the life of the building. The space plan is also within the building envelope and as such will involve aspects of interior environmental quality. Given these parameters the space plan elements can be subjected to a high degree of conflict with other systems. Based upon analysis of residential renovation patterns, floor finish systems experience the highest degree of alterations as well as interior wall configurations. Since flooring materials require a high degree of durability they are subjected to removal and are also viable sources for reuse.

Raised access floor systems

- Raised flooring systems eliminate duct-work and place electrical and telecommunication utilities under a raised floor grid rather than overhead, making them more accessible. The plenum that is created by the raised platform is also an air distribution system. The floor system is created from a modular kit-of-parts that can be easily altered in increments or for the whole floor.

Principles: *separation of MEP from other systems, reduction in materials use, elimination of chemical connections, modularity.*

Carpet tiles

- Carpet tiles are a modular system created of interchangeable square units. They are installed over a smooth substrate with minimal adhesion to allow for ease of removal. Due to smaller standard dimension unit sizes, less waste is created during the installation process. Individual tiles or areas can be replaced as needed from wear, damage or aesthetic preference. These products are available with recycled-content and several manufacturers produce recyclable products. Certain manufacturers also maintain end-of-life programs that allow for take-back of the products to the manufacturer.

Principles: *recycled, recyclable, producer responsibility, modularity, simple connections.*

Organic paints, non-toxic paints and sealants

- Natural, organic and low-volatile organic compound (VOC) paints reduce the toxicity of coatings, thereby reducing the real and perceived risks in reusing painted components. Other compounds, if used, such as mercury may pose future unknown hazards. Given the often necessary use of coatings for performance and aesthetic purposes, but their contamination of material for recycling and, if posing a health hazard, for reuse – the best recommendation for DfD is to use coatings with the least known human and environmental health impacts possible, so as to allow for safe reuse, removal, encapsulation or lastly dispersion within a recycled feedstock.

Principles: *reduce and eliminate toxicity.*

Office partition systems

- Office partition systems are designed to use a defined set of panel and connections components to allow the partitions to be moved, reused and reconfigured to extend the usable life of the products and eliminate landfill waste. These systems are pre-manufactured in component parts that are then fully assembled at the site. These systems use a limited set of connections and rely on pre-installed voice, data and electrical components that in turn use plug and play connection systems.

Principles: *modularity, renewable, reusable, recyclable materials, simple and fewer connections and tools, logistical ease for workers, interchangeable, standardized components.*

Interlocking loose laid flooring

- Click-lock laminated flooring products use a unique tongue and groove configuration that creates an integral connection without the use of nails or adhesives. The flooring is placed together at an angle and then when angled down into the flat position, the curvature of the join pulls the pieces into a locked position. This system allows for ease of disassembly and reuse without special tools and retains the integrity of the materials. As a wood product it can also be potentially recycled and recovered for energy.

Principles: *modularity, eliminate chemical connections, reduce connection complexity, parts, tools, avoid entanglement with other systems, renewable and reusable materials.*

Fig. 79 raised access flooring

Fig. 80 FLOR carpet panels

Stuff_ Traditionally having the shortest lifespan, the ‘stuff’ that makes up interior furnishings is of great priority due to daily use in close contact with occupants and hence potential for human health impacts. As these elements are experienced visually and tactilely at close-range they are also those for which craft and aesthetics at a fine grain are important considerations. Reuse of components from other sources that may contain environmental contaminants is more problematic in the interior environment than for other uses that may be separated from regular human contact. On the other hand, weathering, structural integrity and other functional performance characteristics are of less importance than purely aesthetic concerns.

Commercial furnishing products

- Many “green” furnishings and office systems manufacturers are creating systems of interchangeable components so that items can be repaired and replaced. Examples include chairs designed to be almost completely recyclable, through reuse and recycling of individual components. Aluminum and metal components are 100% recyclable and manufacturers are coding plastic components according to ASTM standards for ease of recycling. Assembly and disassembly systems are designed for ease and interchangeability of standard components, and the fabrics are tested for low-emissions of VOCs and other indoor contaminants.

Principles: *recycled and recyclable, reusable, simpler fewer types of materials and connections, interchangeability and modularity, low to non-toxic materials.*

Residential furnishing products

- IKEA as a corporate entity produces furnishing products in an environmental chain of custody manner including the materials sources, shipping and packaging systems and logistical design to allow for low costs and minimizing environmental impacts. All prodÂucts feature information on their environmental impacts and capabilities of reuse or recycling. Replacing and repairing items is made possible as interchangeable components of the base assembly systems are readily available for purchase from IKEA. Many of the product source materials are chosen for non-toxicity and minimal environmental impacts of resource extraction and potential for effective recycling.

Principles: *renewable, recyclable, reusable, simpler fewer types of materials and connections, logistical ease for worker, interchangeability and modularity, low to non-toxic materials, disassembly information.*

Recyclable and non-toxic fabrics

- The most innovative furnishing fabrics being currently developed are benign in manufacture, use, and end-of-life through

Fig. 81 IVAR chair

materials engineering for non-toxicity, renewability, and recyclability. In general these products are intended to overcome the shortcomings of many manufactured fabrics that must protect against wear, moisture, exposure to UV radiation, etc. through the use of multiple chemical additives, by finding alternative chemicals with lower environmental impacts.

Principles: *non-toxicity, recycled, and recyclable.*

Fig. 82 chair pieces

Natural materials and reclaimed materials or wood

- In general a well-made furnishing object can sustain many lives of reuse through the stoutness of its construction, the quality of wood and other materials, and as it ages, the associations that become attached to it from ownership and use. Ultimately, the most highly prized DfD components will exhibit high quality of craft and material that encourages additional efforts to support their reuse and remanufacture for an extended life. So-called natural materials of wood, grasses, and other fibers, as long as not treated with solvent-based coatings and glues, are good choices for interior furnishings and will be most flexible for reuse and recycling. Using interior furnishings that are reused and not altered will promote long-term materials conservation. The use and reuse of high-quality natural materials will also retain craft-skills from which can be derived the continued maintenance and repair of these objects.

Principles: *reuse, renewable, reusable, non-toxic, elimination of chemical coatings, high-quality materials able to be reused and remanufactured.*

Fig. 83 baobab tree dwelling

Model Deconstruction Specification

PART 1 - GENERAL

1.1 SUMMARY

A. Section includes:
   1. Salvaging items for reuse by Owner.
   2. Deconstruction and removal of building for salvage.
   3. Deconstruction and removal of site elements for salvage.
   4. Removal of selected portions of building for disposal as hazardous materials.
   5. Demolition and removal of selected portions of building or structure for recycling and non-hazardous waste disposal.

B. Related Sections:
   1. Division 01 Section “Construction Waste Management and Disposal” for disposal of demolished materials.

1.2 DEFINITIONS

A. Full Deconstruction: Removal by disassembly of a building in the reverse order in which it was constructed.

B. Selective Deconstruction: Disassembly and removal of selected portions of building or structure.

C. Salvage: Removal of disassembled building materials for the purpose of reuse or recycling.

D. Recycling: Removal of disassembled building materials for processing into secondary materials.

E. Demolish: Remove and legally dispose of off-site.

1.3 MATERIALS OWNERSHIP

A. Unless otherwise indicated, deconstruction waste becomes property of Contractor.

1.4 SUBMITTALS

A. Qualification Data: For deconstruction firm.

B. Schedule of Deconstruction Activities: Indicate the following:
1. Detailed sequence of deconstruction and removal work, with starting and ending dates for each activity.
2. Interruption of utility services. Indicate how long utility services will be interrupted.
3. Coordination for shutoff, capping, and continuation of utility services.
4. Use of elevator and stairs.
5. Locations of proposed dust- and noise-control temporary partitions and means of egress.
6. Means of protection for items to remain and items in path of material removal from building.

C. Inventory: After deconstruction is complete, submit a list of items that have been salvaged, recycled and disposed of and documentation (receipts/scale tickets/waybills) showing the quantities.

D. Deconstruction Photographic Documentation: Document general condition of materials to be salvaged prior to removal.

E. Submit Deconstruction Plan prior to start of work.
1. Plan for environmental surveys and remediation and abatement as needed.
2. Inventory of building materials to be salvaged, whether reuse or recycle.
3. Techniques to be employed for salvage and recycling including, equipment to be used.
4. Environmental health and safety plan including any special conditions.
5. Preliminary list of outlets for each material type to be salvaged, hazardous materials and non-hazardous materials.
6. Measurement and reporting format including reporting schedule.
7. Close-out sequence and activities per contract and regulatory requirements.

1.5 QUALITY ASSURANCE

A. Deconstruction Firm Qualifications: Company(ies) experienced and specializing in performing the Work of this Section with documented experience in similar types of deconstruction work.

B. Regulatory Requirements: Comply with hauling and disposal regulations of authorities having jurisdiction.
  1. Comply with noise and dust regulations of authorities having jurisdiction.
  2. Comply with historical review, environmental, permitting, and hazardous waste management regulations of jurisdictions having authority.

C. Pre-Deconstruction Conference: Conduct conference at Project site. Review methods and procedures related to deconstruction including, but not limited to, the following:
  1. Inspect and discuss condition of building to be deconstructed.
  2. Review structural load limitations of existing structure per engineering survey defined in OSHA CFR 29 Part 1926, Subpart T, 1926,850(a).
  3. Review and finalize deconstruction schedule and verify availability of materials, personnel, equipment, and facilities needed to make progress and avoid delays.
  4. Review requirements of work performed by other trades that rely on substrates exposed by deconstruction operations.
  5. Review areas where existing construction is to remain and requires protection.
  6. Review method for removing materials from the site.
  7. Review staging area for materials on the site.
  8. Review ingress and egress and adjacency conditions that may impact site and that may be impacted by project.

1.6 PROJECT CONDITIONS

A. Hazardous Materials: It is unknown whether hazardous materials will be encountered in the Work.
  1. If materials suspected of containing hazardous materials are encountered, do not disturb; immediately notify Architect and Owner. Owner will remove hazardous materials under a separate contract.

B. Utility Service: Maintain existing utilities indicated to remain in service and protect them against damage during deconstruction operations.
  1. Maintain fire-protection facilities in service during deconstruction operations.

1.7 DECONSTRUCTION PLAN

A. Material Identification: Indicate anticipated types and quantities of materials to be salvaged, recycled, and disposed of. Indicate quantities by weight or volume, but use same units of measure throughout.

B. Procedure: Describe deconstruction methodology, sequencing, and materials handling and removal procedures. Include the anticipated final destination of each material.

PART 2 - PRODUCTS (Not Used)

PART 3 - EXECUTION

3.1 EXAMINATION

A. Verify that utilities have been disconnected and capped.

B. Verify that known hazardous materials have been abated, removed or otherwise remediated.

C. Survey existing conditions and correlate with requirements indicated to determine extent of deconstruction required.

D. Inventory and record the condition of items to be removed and salvaged.

E. Engage a professional engineer to survey condition of building to determine whether removing any element might result in structural deficiency or unplanned collapse of any portion of structure or adjacent structures during deconstruction operations.

F. Survey of Existing Conditions: Record existing conditions by use of preconstruction photographs or videotapes.

G. Perform surveys as the Work progresses to detect hazards resulting from deconstruction activities and make corrections as needed.

3.2 UTILITY SERVICES AND MECHANICAL/ELECTRICAL SYSTEMS

A. Existing Services/Systems: Maintain services/systems indicated to remain and protect them against damage during deconstruction operations, if only selective deconstruction to be performed.

B. Service/System Requirements: Locate, identify, disconnect, and seal or cap off indicated utility services and mechanical/electrical systems.

3.3 PREPARATION

A. Site Access and Temporary Controls: Conduct deconstruction operations to ensure minimum interference with roads, streets, walks, walkways, and other adjacent occupied and used facilities.

B. Temporary Facilities: Provide temporary barricades and other protection required to prevent injury to workers and damage to salvageable materials.
   1. Provide protection to ensure safe passage of workers around deconstruction area.
   2. Provide weather protection and protection from theft for all salvage materials (and items to remain) before, during and after deconstruction.

C. Temporary Shoring: Provide and maintain shoring, bracing, and structural supports as required [to preserve stability and prevent movement, settlement, or collapse of construction and finishes to remain] [and/or to prevent unexpected or uncontrolled movement or collapse of construction being selectively deconstructed].
   1. Strengthen or add new supports when required during progress of deconstruction.

3.4 DECONSTRUCTION

A. General: Deconstruct and remove existing construction in accordance with the materials identified for removal in the deconstruction plan. Use methods required to complete the Work within limitations of governing regulations and as follows:
   1. Proceed with deconstruction systematically, from last materials on to first materials on, from non-structural to structural elements, and from higher to lower level. Complete structural deconstruction operations above each floor or tier before disturbing supporting members on the next lower level.

2. Neatly cut openings and holes plumb, square, and true to dimensions required. Use cutting methods least likely to damage construction to remain or adjoining construction. Use hand tools or small power tools designed for sawing, prying or grinding, not hammering and chopping, to minimize disturbance of adjacent surfaces. Temporarily cover openings to remain as required.
3. Cut or drill from the exposed or finished side into concealed surfaces to avoid marring existing finished surfaces.
4. Do not use cutting torches until work area is cleared of flammable materials. At concealed spaces, such as duct and pipe interiors, verify condition and contents of hidden space before starting flame-cutting operations. Maintain portable fire-suppression devices during flame-cutting operations.
5. Maintain adequate ventilation when using cutting torches.
6. Remove decayed, vermin-infested, or otherwise dangerous or unsuitable materials and promptly dispose of off-site in accordance with all federal, state and local regulations.
7. Remove structural framing members in such a way as to maintain their highest value.
8. Locate deconstruction equipment and remove debris and materials so as not to impose excessive loads on supporting walls, floors, or framing.
9. Dispose of demolished items and materials promptly.

B. Salvaged Items:
1. Sort and organize salvaged materials as they are removed from the structure.
2. Pack, crate or band materials to keep them contained and organized.
3. Store items in a secure and weather protected area until removed from the site or transferred to Owner.
4. Transport items to Owner’s long-term storage area, either off-site, on-site as designated on construction drawings, if Owner to retain ownership of salvaged materials.
5. Protect items from damage during transport and storage to off-site storage if Owner to retain ownership of salvage.

C. Existing Items to Remain: Protect construction indicated to remain against damage and soiling during selective deconstruction activities. When permitted by Architect, items may be removed to a suitable, protected storage location during deconstruction and cleaned and reinstalled in their original locations after selective deconstruction operations are complete.

3.5 DISPOSAL OF DEMOLISHED MATERIALS

A. General: Except for items or materials indicated to be recycled, reused, salvaged, reinstalled, or otherwise indicated to remain Owner's property, remove demolished materials from Project site and legally dispose of them.

1. Do not allow demolished materials to accumulate on-site.
2. Remove and transport debris in a manner that will prevent spillage on adjacent surfaces and areas.
3. Remove debris from elevated portions of building by chute, hoist, or other device that will convey debris to grade level in a controlled descent.
4. Comply with requirements specified in Division 01 Section "Construction Waste Management and Disposal."

B. Burning: Do not burn demolished materials.

3.6 CLEANING

A. Clean adjacent structures and improvements of dust, dirt, and debris caused by deconstruction operations. Return adjacent areas to condition existing before deconstruction operations began.

3.7 SALVAGED MATERIALS FOR REUSE BY OWNER SCHEDULE

A. Existing Items to Be Removed and Salvaged:

<Insert description of items to be removed and salvaged for reuse by Owner.>

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