Steel is Sustainable Construction

Design for Deconstruction

By Michael Pulaski, Christopher Hewitt, Michael Horman, Ph.D. and Bradley Guy

The complete sustainable-design cycle includes provisions for the re-use of building components at the end of a structure's design life.

Designing for deconstruction or disassembly is an important part of green design and the closed-loop building materials cycle. Material waste produced from new construction, renovation and demolition is 25%-30% of the total waste produced each year in the United States and U.K. (EPA 1996). Of this waste stream, 92% is from renovation and demolition and 8% is from new construction. Many products that are sent to the landfills have a salvage value that can generate a profit from the demolition process, or at at least eliminate the tipping fees paid to landfills to accept the disposed material. As salvage markets continue to grow, economic and ecological conditions are likely to dictate that today's buildings be preserved, refurbished, reused or broken down into salvageable and reusable components rather than demolished at the end of their useful life. In this scenario, buildings designed for deconstruction will have the greatest value (Fishbourne 1998).

There is also a distinct connection between design for deconstruction and design for constructability. Constructability analysis during building design simplifies the construction process, and can be extended to address deconstruction issues. If a building can be constructed simply, it probably can be deconstructed simply. Examples of relevant constructability principles include prefabrication, modularization, and simplification of connections and building systems. By using similar principles to simplify the initial construction of a building and its end-use deconstruction, the recovery of building materials at the end of a building's life can be considered at a reasonable cost.

Design for Reuse

Design for Deconstruction increases efficiency in a building's adaptability and disassembly, while reducing the impact of pollution and recovering building materials for reuse and recycling. To improve the efficiency and economic benefits of deconstruction, design elements that simplify the disassembly effort and reduce the labor hours required for processing (moving disassembled materials to storage locations) should be incorporated.

Some obstacles include worker safety and health hazards, site storage for recovered materials and lack of standards for certain recovered materials. Design for deconstruction also must consider the rapid removal of a building from the site, simplified access to components and materials, material recovery with high efficiency of reuse and recycling, and eliminating toxicity in building materials. By meeting these goals, Design for Deconstruction facilitates a "closed-loop" material recovery and reuse process.

Constructability

Constructability concepts and practices in the initial design of a building have value to add to the life-cycle efforts of sustainable design, sustainable construction and deconstruction efforts. To successfully incorporate constructability practices into a design, input must be considered from all project players. By identifying best practices from all of the various designers and contractors on the project, the team can provide practical guidance for effectively incorporating building-wide deconstruction principles into the design process.

Common Principles

Much of the research and practice that has been applied to improve constructability is also applicable to deconstruction. Ten well-documented principles that are complimentary to both follow below.

Design for Prefabrication, Preassembly and Modular Construction. Prefabricated units like pre-cast concrete floor panels are beneficial during deconstruction if the units can be dismantled from the structure in large sections and transported offsite to reduce the deconstruction schedule. Easily stackable units, like cladding systems, curtain walls and steel beams, can reduce transportation costs to off-haul materials. This type of design can result in reduced construction costs and schedules, and increased construction quality. Potential assemblies could include steel trusses, prefabricated wall systems, pre-cast panels for walls or floor systems, and modular structural systems. A good practical resource for implementing this principle is the *Decision Framework Guide and Tool for Prefabrication, Preassembly, Modularization and Offsite Fabrication*, developed by the Construction Industry Institute.

Simplify and standardize connection details. Simple and standardized structural connections can enhance the assembly and disassembly process. For example, modular connections allow steel members to be easily disassembled and reused. Two examples of this are some systems that are being explored in steel castings, and an older system called Saxe clips. Simplified, modular connections can require as few as one bolt and no welding for installation, easing the construction process.

Complex and unique connections increase installation time and complicate deconstruction. Fewer connections and consolidation of the types and sizes of connectors reduce the need for multiple

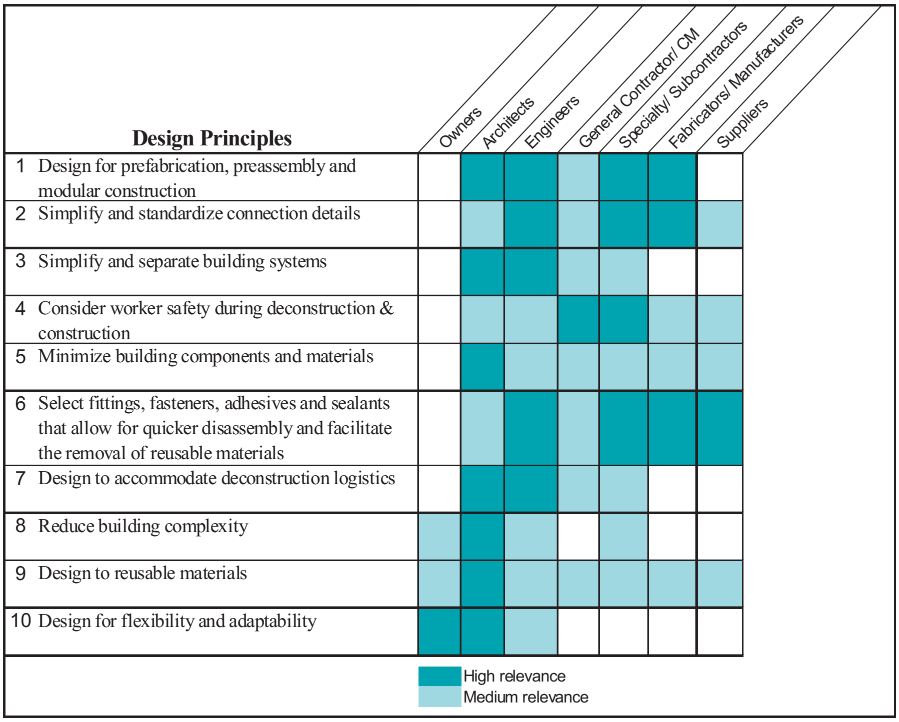

Figure 1. Application Matrix for Project Team Members. It identifies the project players that have the ability to enhance a specific design principle.

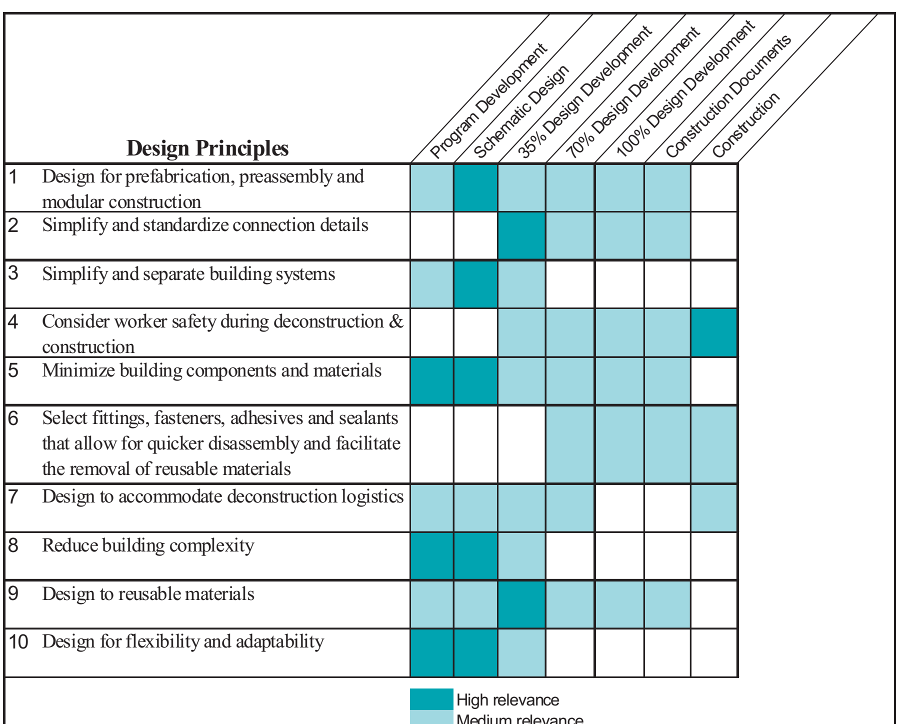

Figure 2. Application Matrix for Design Phases. It identifies the appropriate time to address each principle.

tools during deconstruction. Simple and standard connections facilitate the ease of disassembly and full recovery of reusable materials.

Simplify and separate building systems. The entanglement of MEP systems within walls, floors and ceilings can impede the separation of building components during deconstruction. Separating distribution systems (ductwork, wiring, communication cables, etc.) in non-structural walls can allow for selective demolition of these low-value components. Consolidation of plumbing service points reduces points of entanglement and the length of piping runs. Simplified designs reduce oversized components, avoid unnecessary transitions and could create separate plenum zones for each distribution system to facilitate separation during deconstruction.

Simplification and consolidation of building systems also have first cost and constructability benefits. A simplified exhaust shaft design on the Wedge 1 Pentagon Renovation project saved $782,000 by eliminating transitions, reducing installation error, and allowing room for future flexibility.

Consider worker safety. Design to reduce or eliminate safety hazards and the use of potentially hazardous materials. Eliminate or alter design elements that require potentially dangerous/ hazardous construction and deconstruction activities such as scaffolding, fall protection and respiratory protection. Specific strategies include built-in tie offs and connection points for machinery, external fittings around façade to attach scaffolding, minimize overhead work, and design to members that are consistent in size, light weight and easy to handle (CII 1996).

One example of safety improvements comes indirectly from a process-oriented manufacturer who developed a lighting fixture that significantly reduced the amount of overhead work during construction by including features such as pre-wiring, mated plugs and a simplified clip-on mounting system. These improvements reduced installation time and construction-safety hazards. The simplified and consolidated design reduced total installed cost, shortened lead time from four weeks to 10 days and allowed for easy disassembly (Tsao & Tommelein 2001).

Minimize building components and materials. Design for the minimum amount of building materials and equipment necessary. Specific strategies include: open-bay design reduces interior partition walls and provides future adaptability; structure and finished-grid layout should harmonize to minimize waste during installation; and structural elements can be used as finished materials, like architecturally exposed structural steel. Reducing the number and size of building components lowers first costs, minimizes resource consumption and expedites the deconstruction or future retrofit process.

Select fittings, fasteners, adhesives and sealants that allow for quicker disassembly and facilitate the removal of reusable materials. The reuse of finished materials and building components depends on their connections with other components. Materials fastened by chemical sealants and standard adhesives require special attention during deconstruction, increasing disassembly time and cost. Mechanical fasteners and releasable adhesives allow for quick and clean material recovery, improved reusability, reduced toxicity and even reduced initial construction costs.

The next generation of hazardous materials is expected to include fibrous insulations, chemical treatments for wood, and many synthetic materials used such as sealants, chemical coatings, binders and adhesives. First costs and constructability considerations have been realized by choosing systems like mechanical fasteners for piping connections instead of soldered joints, reducing installation costs by 20% (Rigid ProPress System 2003).

Design to accommodate deconstruction logistics. Site access and waste removal are cost drivers during deconstruction. Small design alterations, such as the installation of lift shafts, can improve waste-removal efficiency. Initial construction-cost savings can be realized by using lift shafts as man or material lifts, or for tower-crane placement. During deconstruction, lift shafts can be used to move materials down through the building efficiently (Fletcher, Popovic & Plank 2000). During the operation phase of the building, lift shafts can be used as recycling shafts.

Reduce building complexity. Buildings with complex structural elements such as pre-stressed and post-tensioned beams, cantilevers and undercuts are more difficult to deconstruct (Fletcher, Popovic & Plank 2000). Reducing complexity will improve first costs and constructability while simplifying the deconstruction process.

Design to reusable materials. Select materials that will stand the test of time and are adaptable for future uses. Composite materials, like the loose and bonded insulation found in curtain-wall systems, make the deconstruction process more difficult (Fletcher, Popovic & Plank 2000). Materials such as wood flooring, steel members, brick, CMU blocks, and carpet tile can be easily and directly reused, refurbished or recycled. This increases material life and reduces the environmental impact of harvesting new materials.

For example, recycled steel takes 75% less energy to produce than virgin steel. By adapting a structural design to allow steel members to be reused or recycled, initial harvesting energy is saved for a material that can be recycled an infinite number of times.

Used products are sometimes less expensive than new materials, which can help reduce first costs, but be careful to ensure that used or reclaimed products are available locally.

Design for flexibility and adaptability. Design to accommodate future renovations and extend the useful life of buildings. The use of open-space offices with modular wall-panel systems enhances flexibility and adaptability for reconfiguration. While some elements of flexibility could increase first costs, other elements, such as open layouts and reduction of interior partitions, can help to improve constructability and reduce costs.

Timing is Everything

The timing of design decisions is critical to project success. Decisions made too early limit design options, while late decisions result in design re-work and create animosity. To develop insight on the timing of and sources for deconstruction decisions in design, 12 industry professionals completed a two-part survey. They were asked to identify which team members had valuable information to contribute to each design principle and to determine when it was appropriate to address each principle. Analysis of the survey results lead to the following findings:

- The most appropriate time to address the majority of design for deconstruction principles is during Schematic Design and 35% Design Development.
- Architects were perceived to have the greatest influence upon and input into design for deconstruction principles, followed by engineers.
- The top two design principles were "Design for prefabrication, preassembly and modular construction" (Principle 1) and "Minimize building components and materials" (Principle 5). These two principles had the highest overall ratings on both parts of the survey. They are consistently addressed throughout design and most of the project players have relevant information to contribute to these two principles.

Case Study

One example of the reuse of steel is the Roy Stibbs Elementary School in Burnaby, Canada. On Dec. 28, 1993, the classroom wing of this school was completely destroyed by fire. The staff and students were relocated to the former Marian High School in Burnaby to which the students traveled by bus each day. A new school needed to be built quickly. The design team immediately was able to obtain the steel members from an abandoned steel-framed secondary school in the mining town of Cassier in Northern British Columbia. The secondary school was dismantled and 75% of the structure was sent to the project site for use in the new facility. The structure was re-erected using the original shop drawings. An independent materials-testing consultant was used to ensure that any damage caused by the dismantling or transportation was identified properly and repaired. Higher seismic and snow loads were met through the addition of chevron braces. Ultimately, the contractor was able to save five months off of the project schedule by salvaging the steel members.

This kind of disassembly and re-erection is most practical when the structural system avoids monolithic components, and uses easily demountable components, such as non-composite structural steel or un-topped precast concrete. By relying on mechanical fastening rather than chemical bonding methods (welding, etc.) the connections can be disassembled easily. European buildings commonly use all-bolted structures to promote material reuse and to simplify demolition at the end of a building's life.

Conclusion

Most design for deconstruction principles will lead to lower deconstruction, material recovery, and life-cycle costs.

The more principles associated with constructability and first-cost savings, the more can be incorporated into today's designs.

Constructability concepts and practices have not traditionally been regarded as value-added components to sustainable design. As the industry begins to recognize the value in these concepts, green buildings will become more cost effective and more deconstructable. This research is part of the "Lean and Green" research program (**www.engr.psu.edu/leanandgreen**) at Penn State. The program is focused on applying the waste eliminating principles of lean production into the project processes of green projects to create high performance processes that yield high performance buildings.

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The following are among the reference materials used to write this article. A complete list is included with the original article.

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