# *Achieving Sustainability through Durability, Adaptability, and Deconstructibility*

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A building's life-cycle environmental impact includes both operational and embodied components. Operational impacts are those such as energy consumption that occur during use, while embodied impacts are mostly due to the production and installation of the building's materials. An example of an embodied impact is the pollution released during the extraction, manufacture, and installation of a building component. The longer a building remains in service, the smaller the embodied impacts are per year of service. Therefore, efforts to minimize embodied impacts must also include strategies to increase service life. This article discusses the validity of common service life assumptions, and challenges design professionals to achieve greater sustainability by incorporating durability, adaptability, and deconstructibility in their designs.

A 50-year lifespan is often assumed for common building types such as commercial buildings and schools. However, many buildings are demolished when they are well short of 50 years of age, often for reasons other than material degradation. Premature demolition and replacement of buildings impacts our environment in many ways, from the disposal of demolition waste to the need to manufacture and install new materials. While many designers have started to specify recycled content materials, this is only a first step. Recycled materials, even those that contain 100% recycled content, still may have significant embodied impacts. In an attempt to increase longevity, some may be tempted to specify more robust or "durable" materials, but durability may not be the best strategy to increase building life.

A 2004 study by The Athena Institute surveyed buildings demolished in St. Paul, Minnesota from the period of 2000 to 2003. While the study was partially motivated by a desire to understand the relationship between structural materials and building longevity, it revealed that the three most common reasons for a building to be demolished were: area redevelopment (34%), lack of maintenance (24%), and building no longer suitable for intended use (22%). These findings show that most of the buildings were demolished not due to durability problems, but rather due to poor adaptability.

The study also found that the building longevity was not highly dependent on the structural material used to construct the structural frame. Some of the oldest demolished commercial buildings were wood-framed and most of the younger buildings were steel or concrete. Over 60 percent of the concrete buildings demolished were less than 50 years old, with roughly 10% being less than 25 years old. The results were more striking for steel buildings; 80% of those buildings were less than 50 years old, with 40% being less than 25 years old.

This limited survey shows that there are a number of reasons why a building may be demolished, with many reasons completely unrelated to material durability. For modern buildings, the building's lifespan may be considerably shorter than an assumed 50-year span. Furthermore, since in most instances the structural system does not "wear out," it can have considerable residual value at the end of a building's life. The application of Design for Deconstruction, Design for Durability, and Design for Adaptability can help extend the life of structural materials, both within a current project, and as salvaged materials in future projects

*Figure 1: The Chartwell School, Seaside, CA, designed by EHDD Architecture with Tipping + Mar Associates as structural engineer. Courtesy of Michael David Rose / MDRP.NET.*

## Design for Adaptability (DfA)

Adaptability is the ability of a structure to accommodate varied and often unknown future uses and changes with minimum of cost and effort. DfA can extend the life of a building by making it easier to adapt it to new uses. The Athena study found that 22% of the buildings were demolished because they were no longer suitable for their needs.

Many strategies for adaptability are the same as the strategies for deconstruction, which is discussed later. These strategies focus on simplicity, repetition, transparency, and so on. Those who have worked on existing buildings know how important an easily comprehensible structural system is to the success of adaptive reuse projects. Complex structural systems with concealed conditions increase the adaptation costs because the structural investigation is more expensive and uncertainties about component capacities lead the engineer to take a more conservative approach. When the building code prescribes a minimum lateral load capacity for reuse projects, uncertainty about the existing lateral-load-resisting system could lead to extensive investigation or unnecessarily costly upgrades to the system.

DfA is most important for buildings that are likely to undergo changes in use over their lives. Good candidates are:

- office buildings, where tenants frequently change;
- schools, where changing demographics and educational requirements often lead to school building decommissioning;
- industrial buildings; and
- churches (other than elaborate cathedrals), where congregations come and go.

Iconic buildings such as certain museums and cathedrals are likely to remain more static over their lives and are less likely to benefit from DfA.

Some building types are likely to be short-lived and are inherently difficult to adapt, such as commercial strip malls in growing suburbs. These types of structures are best designed simply for deconstruction and material reuse, with sufficient durability to protect the materials through their projected short life.

*Figure 2: Rinker Hall, The University of Florida, designed by Croxton Collaborative Architects and Gould Evans Associates with Walter P Moore as structural engineer. Courtesy of Chroma, Inc.*

A sampling of DfA strategies for building structures includes:

- Designing using higher-than-code-minimum live loads when future uses may require them;
- Providing redundancy and resiliency in the lateral system in case future adaptations require changes such as new openings in shear walls; the Chartwell School (*Figure 1*) used shear walls with extra capacity along the main corridor in case new doorways to reconfigured classrooms are needed in the future;
- Consideration of how the building may be expanded in the future, such as sizing foundations and columns for vertical additions; and
- Coordination of the structural system with other building systems to ease future renovation; Rinker Hall (*Figure 2*) routed all basic mechanical and electrical systems along a "highway," coordinated with and running parallel to the north-south structural system.

Just as mechanical systems become obsolete over time due to changes in technology, structural engineers confront the potential for obsolescence as new technologies arise to resist seismic forces, and older systems are found to be inadequate. Buildings with obsolete and unsafe lateral-load-resisting systems may be retrofitted with new technologies to improve their performance. In many retrofit strategies, the gravity-load-resisting system remains in service, while the lateral-load-resisting system is strengthened, supplemented, or even replaced. As such, one DfA approach to structural systems would be to plan for future changes to the lateral system. Possible strategies include making the lateral system independent of the gravity load system and using components such as braces that can be easily swapped out.

## Design for Durability (DfDr)

Should we always design our buildings for maximum durability? Or are there cases where lesser durability would suffice? Actual building life is often much less than predicted life. Many buildings also survive much longer than predicted, although this scenario appears to be less common, at least for non-residential buildings. Given the difficulty of forecasting building life and the permanency of the structural system, it makes the most sense to design the structure for enough durability to ensure that it is not the weak link that results in a building's demise. The 2004 Athena demolition survey suggests we are typically meeting this objective already. Buildings in this small study were for the most part not demolished as a result of deterioration of the structural system. Nevertheless, we should strive to ensure that deterioration of the structural system is never the cause of a building's demise. Since the building envelope often protects the structural system, the structural engineer should understand envelope systems and work with the envelope designer to develop an integrated structure-envelope design that will ensure the long life of the structural system. Where envelope systems have a shorter predicted service life than the structural system, the envelope system should be designed to be easily removed from the building structure and replaced.

Canadian Standards Association (CSA) Standard S478, *Guideline on Durability in Buildings*, defines the concepts of "design service life" and "predicted service life." The design service life is "specified by the designer in accordance with the expectations (or requirements) of the owners of the building." The predicted service life is the service life "forecast from recorded performance, previous experience, tests, or modeling." The design goal outlined in the standard is for the predicted service life of the building, and its components and systems, to meet or exceed the design service life.

Using the DfDr approach outlined by the CSA standard, one might attempt to match the predicted life of the structural system to the design life of the building. However, designing the structural system of a building with a short predicted life for less durability than the system for a building with a longer predicted life carries risks:

- The building may actually last longer than predicted, risking deterioration of the structural system before the building reaches the end of its life; and
- Even if the building life matches the predicted life, the structural materials may have begun to deteriorate and may no longer be suitable for reuse.

Once one accepts that closing the materials loop calls for deconstruction of buildings at end-of-life and reuse of materials, DfDr of the structural system becomes paramount for all buildings, whether they are predicted to have a short or long life.

## Design for Deconstruction (DfD)

Materials sustainability depends upon "closing the materials loop," meaning the material life-cycle is circular (use → collect → process → reuse) rather than linear (extract →manufacture → use → discard). Deconstruction, a demolition method where a structure is carefully and methodically disassembled so as to salvage as many components as possible, is a key step in this circular life-cycle. DfD is a design strategy intended to facilitate future deconstruction. Though rarely used today, DfD is arguably the most important green design strategy for achieving material sustainability through closing the materials loop. Durability and adaptability may never be required for buildings that, due to factors such as neighborhood changes, have a short life; however virtually all buildings will eventually be replaced or removed, so facilitating deconstruction and material reuse will almost certainly be useful.

Most of the buildings presently under construction will likely be gone in less than 50 years. In some cases, such as The Discovery Center at Lake Union, Seattle, WA (*Figure 3*), a structure may be constructed with the understanding that its service life will be as short as a few years. Monumental buildings, on the other hand, such as elaborate cathedrals, museums, and other important public and institutional buildings, likely will survive much longer. The environmental benefit of reusing materials from common short-life buildings is greater than the benefit from less common long-life buildings, both due to the relative numbers of these building types, but also because the impact of the wasted materials averaged over the life of the building is less for the long-life buildings. Nevertheless, DfD is good practice for all buildings, because actual building life is highly unpredictable.

*Figure 3: The Discovery Center, South Lake Union, Seattle, WA designed by The Miller|Hull Partnership with Magnusson Klemencic Associates as structural engineer. Courtesy of Magnusson Klemencic Associates.*

The structural system, as the bones of a building, is generally the most permanent part of the building system. As such, when a structural system is deconstructed, it is typically at the end of the building's life, which is a consideration when designing the structure for deconstruction. Other building systems will typically already be removed before work begins on deconstructing the structural system. A thorough designer for deconstruction will consider how the structure will be disassembled. What type of equipment will be utilized? Where will the workers be situated during the work? Could the initial structural design be tailored to improve safety and stability during disassembly?

Little incentive exists in today's construction market to design for deconstruction. LEED®, the most popular green building rating system, does not reward DfD in its standard credits. LEED Innovation Credits may be applied towards DfD, but to the authors' knowledge no team has successfully obtained LEED credit for DfD. Green Globes™, another green building rating system, offers up to three points for designs allowing the removal of reusable materials without damaging the surrounding materials, but this rating system is not widely used.

DfD should increase the value of a building for two reasons: the building will be easier to modify and improve during its useful life; and, at the end of its life the salvage value of its constituent materials will be higher. The materials will have been selected for their reusability and connected together so as to be easily separable for reuse. For this reason, the building will be valued not just for its location, functionality, and aesthetics; it also will have inherent value in its constituent parts.

A combination of green building rating system incentives, price increases for new materials, and possibly tax or regulatory incentives could drive the demand for DfD. Market forces alone are not sufficient at this time. It is difficult to convince building owners to implement design features when the return on investment is perceived to be realized only at the end of the building's life. Changes are also needed in materials handling. For example, suppliers will need to start stocking used materials in addition to new materials. Deconstruction specialists will need to develop efficient techniques for dismantling buildings, and will need markets for the used materials. Materials labeling, perhaps following the model of wood grading, will help designers and consumers identify the strength and quality of used materials. Higher demand for used materials will drive the development of markets, which is where green building rating systems and government incentives could help, until future scarcity of resources and increased energy prices drive up the cost of new materials.

## Conclusion

The Athena demolition study is an important start to developing a better understanding of the types of buildings that are likely to have long lives and why. More studies of this type are required for structural engineers and other building design practitioners to create effective strategies to increase building life and facilitate reuse of building materials.

While the concepts discussed here are not currently rewarded in LEED, projects embracing these strategies have been recognized by other green building organizations such as the American Institute of Architects Committee on the Environment (AIA COTE) Top Ten Green Projects and the EPA's Lifecycle Building Challenge (**www.lifecyclebuilding.org**). More details on each project, as well as other winners, can be found at **www.aiatopten.org**.▪

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The committee website is **www.seinstitute.org/committees/sustainable.cfm**.