

ANTICIPATING AND RESPONDING TO DECONSTRUCTION THROUGH BUILDING DESIGN

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SUMMARY

The construction and demolition industry produces vast quantities of waste that for environmental, economical and social reasons is becoming unacceptable. The extended chain of responsibility and the separation of responsibilities for manufacturing materials, design and construction, operations and maintenance, and eventual adaptation or disposal, have resulted in a breakdown of feedback loops among the parties involved in creating and operating the built environment. To effectively tackle this waste issue a more proactive design approach must be taken. By designing both building products and buildings for deconstructability, architects and other designers are enabling the extraction of high value materials for reuse and recycle. As there is logic in design and erecting a structure to serve a particular purpose, there should also be logic to its removal when the structure is done serving that purpose. Initial design and future deconstruction should relate to each other clearly and coherently. Designers should also have the aim of achieving the best possible disassembly. To address the challenge of how to come up with a deconstruction friendly design, a building is broken into its constituent components from foundation to the roof and then design criteria for each of these elements is suggested in a manner that would facilitate easy disassembly of the building, eventually leading to more components reuse.

KEYWORDS: Deconstruction, Recycle, Reuse, Disposal Phase, Sustainable Construction, Demolition, Construction and Demolition (C&D) Waste

INTRODUCTION:

Functional architectural concepts along with aesthetic sensibility have now replaced formal ones of the past. Functional buildings can be defined specifically by their use, a link between the free creations of architects and the bare utilitarian structures of engineers and technicians. Fulfillment of purpose has become one of the means of architectural design. Architects nowadays try to exploit the possibilities of functionalism to the full and the concept of ‘designing for deconstruction’ needs to be an integral part of this functionalism. Thus, if a building is said to be functional, it should not only satisfy the requirements for its intended use but it should also be responsive to its disassembly at the end of the life cycle. Typically, a building project includes five phases where it is possible to identify and apply waste prevention techniques. Some of these phases overlap with each other, because decisions made during the early stages will affect the later stages, but they can still help to clarify what necessary steps constructors can take at various instances in a project. The different phases involved and their related waste prevention objectives are listed below [1]:

- **Asset management:** To assess and make sure that existing buildings meet current needs and to optimize the use of existing and available properties to meet those needs.
- **Project planning:** To formulate a waste plan and set waste prevention goals.
- **Design:** To design the proposed structure in a manner such that, it's components address the issues of reusability, durability, and adaptability.
- **Construction:** To promote and achieve efficient procurement of materials, delivery, storage, and eventually the effective use of those materials on the jobsite.
- **Demolition:** To continuously encourage the philosophy of deconstruction and salvage of materials for future reuse, instead of total destructive demolition.

If we look back into history it is evident there has been a long established culture of reuse and recycling of building materials and, in the industrially backward societies this is still applicable today. The majority of vernacular buildings used materials that were easily available in the surrounding locality and were true to the geographic prevailing geographic conditions. Materials such as stone, slate, timber, thatch, and mud were used and these were allowed to decay naturally or could be easily reworked into newer buildings [2]. Old materials tend to have an aesthetic, authentic and antiquarian value, and are have always been considered as elements that add value to a property. Design for disassembly is not a new idea. History also tells us that traditional Japanese farmhouses were constructed without nails, and could be disassembled and reassembled like a puzzle. [3] The building industry is beginning the first steps in formalizing some of the strategies that would create benign processes, close materials loops, and make industrial systems mimic and integrate with natural processes. The writings, and the built work, of Brenda and Robert Vale illustrate a number of 'green' architecture principles that could be constituted into sustainable architectural practice. There are six basic principles that have been suggested [4], and one of them is:

- *Minimize new resources*, a building should be designed so as to minimize the use of new resources and, at the end of its useful life, to form the resources for other architecture.

Design for deconstruction is an attempt to raise materials and components up the recycling hierarchy, away from recycling, and up to a more environmentally preferable point of reuse. For these reasons design for disassembly is primarily, but not exclusively, an issue of design for the reuse of materials [4].

DESIGN FOR DECONSTRUCTION STRATEGIES

To successfully implement the concept of component reuse, the owner or the owner's representative should in the first instance put in place a program which clearly specifies the primary objectives and allows deconstructability to be assessed as a project performance attribute. The essence of this approach is that design for deconstruction and

the eventual building component reuse can be enhanced by individual participants exploiting construction knowledge to maximize opportunities and develop best options to meet project objectives in coordinated way. Although setting a mechanism in place that facilitates deconstruction principles among project team members is an important aspect of implementing deconstruction, it is equally important to recognize the significance of the timing of the input by the various team members. The importance of timing is illustrated by the Pareto principle, which contends that decisions taken at the early stages in the project lifecycle have greater potential to influence the final outcome of the project than those taken in the later stages.

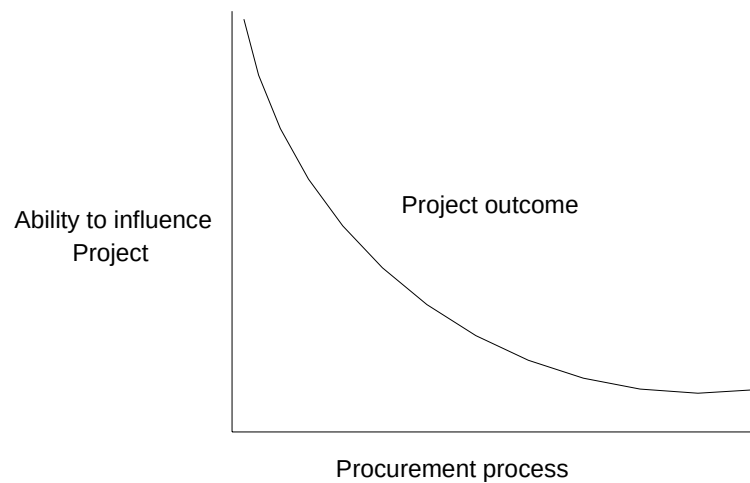


Figure 1 - Cost influence/Pareto curve

The following guidelines can be used to assess the extent to which a building can be designed for material recovery [5]. Each building project is unique and hence there can be no universal strategies that will always apply. These guidelines are presented as a starting point in thinking about design for deconstruction.

- Minimize the number of different types of materials. The more homogeneity there is between the materials of a structure the more simple it would be to sort materials on site and reduce transport to separate the reprocessing plants.
- Design for locally produced building materials.
- The designer should strive for optimal use of interior space through careful design so that the overall building size and resource use in constructing and operating the building is kept to minimum.

- Use detailing that will prevent soil contact and rot.
- Hazardous or toxic materials should be avoided. This will reduce the potential of contaminating materials that are being sorted for recycling and will also reduce the potential for human health risks during disassembly.
- Inseparable subassemblies should be made from the same material. This means that large amounts of one material will not be contaminated by small amounts of foreign materials that cannot be separated.
- Nails and bolts have appropriate uses as per the type of connection and size of the members. A variety of nails in one building cause the requirement for multiple tools for removal. A mix of bolts, screws, and nails requires constant shifting from one tool to the next.
- Permanent identification of material types should be provided. Many materials like plastics are not easily identified and should have some form of non-removable and non-contaminating identification mark to allow future sorting of materials.
- It is essential that all information on the building manufacture and assembly process be sustained. Ample measures should be taken in order to ensure the preservation of information such as 'as-built drawings', information about disassembly process, material and component life expectancy, and maintenance requirements.
- The simultaneous creation of a deconstruction plan along with the construction plan and labeling of components to their constituent materials, similar to plastic products label numeric codes to indicate the type of plastic will provide directions to the deconstruction contractor for the disposition of materials. An upfront deconstruction plan also allows for planning the management, scheduling and safety requirements of the deconstruction process.
- Provide realistic tolerances to allow for movement during disassembly. Handling during disassembly may require greater tolerances than the manufacture process or the initial assembly process.
- Use a hierarchy of disassembly related to the expected life span of the components. Components with shorter life span should be made readily accessible and easy to disassemble, whereas components with longer life spans may be less accessible.
- The project program should make use of optimum value engineering.

BLUEPRINTS FOR DECONSTRUCTION

In order to suggest strategies for designing for disassembly that result in component reuse, which is the core aim of this paper the following guidelines are suggested. Here a typical building has been broken down into its constituent components and suggestions

have been made for each of these components. A building typically consists of the following layers:

- a) Structure – foundation and load bearing components
- b) Skin – cladding and roofing system
- c) Services – electrical, hydraulic, HVAC (heating, ventilating, and air conditioning) etc
- d) Space plan – interior e.g. partitions, finishes and furniture

Structure

Foundations

- The entire load of the building, including the dead loads of the components and the live loads of the occupants is ultimately transferred to the foundation. The foundation then disperses this load evenly to the ground base. In order to facilitate deconstruction foundations have to be designed to receive meticulously calculated loads. The general trend is to over-design the foundations with a higher factor of safety, because the owner at the project inception stage is really not sure about the future occupancy rate of his building. In order to achieve design for deconstruction goals, the owner or the owner's representatives must have a clear picture of the intended purpose of the building and any future additions to it, the loads of which have to be transferred to the existing foundation.
- Building 'thin-wall foundations' can reduce concrete usage by 20%. 'Thin-wall foundation' consists of a 6-inch foundation wall instead of the conventional 8-inch wall. This has been used primarily in residential construction till now, but, can also be applied to commercial and government projects, as long as they abide by the building codes [1].

Structural system

- A good way to think in terms of deconstruction-friendly structural system is to identify, which parts of the building can be self-supporting.
- Use a standard structural grid. Grid sizes should be related to the materials used such that structural spans are designed to make most efficient use of material type.
- It is advisable to keep the geometry of the building simple (Figure 1).



Figure 1 – Simple geometry in building design.

- Portals, which are essentially a combination of vertical and horizontal members, can be used in designing supporting systems. These in turn can be bolted to floor structure (Figure 2).



Figure 2 – Portals enable clear span solutions

- Use assembly technologies that are compatible with standard building practice. Specialist technologies will make disassembly difficult to perform and may require specialist labor and equipment that makes the option of reuse less attractive. Bolted connections favor deconstruction as compared to welded connections. When welded connections are dismantled, for example using a cutting torch, some damage to the connections will occur and there is also a loss of some material. In addition to the possibility of causing a fire hazard, disassembly involving the cutting of welded connections results in a level of uncertainty as to when the connection no longer has sufficient integrity to form a viable structural support. [6]
- Steel is a material with great utility for design for deconstruction, due to its ease of recycling through a thermal process and ability to span large distances with less mass of material than concrete for instance.

- Separate the structure from the cladding, the internal walls, and the services. This will facilitate parallel disassembly where some parts of the building may be removed without affecting other parts. This will result in the saving of sufficient amount of time.
- Buildings designed to incorporate pre-stressed and post tensioned beams, and cantilevers make the demolition process more onerous due to the presence of these complex structural elements. Stressed components pose danger to de-stress.
- Another option available when designing the structural framework for a building is Pre-engineered building. These are well known for their wide clear spans that easily accommodate production lines and changing floor layouts. Their flexible interior space facilitates storage and movement of equipment, allowing customized plant flow. Pre-engineered buildings up to 70 meters clear span and 30 meters eave height could be designed, manufactured and erected. Pre-engineered buildings are site bolted, it is relatively easy and economical to dismantle the buildings and re-erect them in another location.

Floors

- The building should be designed for standard ceiling height and standard building dimensions.
- Precast concrete floors separate the plane of the top and bottom of the wall from the plane of the floor structure facilitates mechanical separation and structural stability during the deconstruction process. In this system the walls sit on top of the floor structure and do not extend through the horizontal plane of the floor structure and the floor above rests on top of the wall.
- Raised flooring systems facilitate deconstruction by eliminating ductwork and placing wiring systems in a more accessible location in the floor plenum rather than the overhead ceiling plenum. This individual item may cost more than traditional practice but facilitates adaptability and energy efficiency (Figures 3 and 4).



Figure 3 – Access floor seen from above



Figure 4 – Access floor seen from below

Skin

Walls

- Use an open building system. Modular wall panel systems have been a major innovation in design for disassembly, which has already affected the construction industry. These replace fixed walls that make the space layout very rigid, with flexible systems that facilitate the reconfiguring of the usable space by mere disassembling and then reassembling the components. The systems also allow for simple replacement of any damaged sections [1]. According to Don Bauman, a systems-marketing consultant at Steelcase Inc., movable wall panels save time on installation and renovation, which results in money saving (Figure 5). Also, installing movable wall panels is 10 to 20 times faster than installing a standard gypsum board drywall system and that reconfiguring these panels does not even disrupt the HVAC systems (Figure 6). Using movable panels to separate work areas does not entail expensive and lengthy electrical and cabling enhancements or alterations; rather, power and communication systems can easily be added directly to the panels. This allows for great flexibility in the layout of office furniture. Considerable savings can also be achieved through reduced maintenance [7]. This will allow alterations in the building layout through the relocation of components without significant construction work.



Figure 5 – Movable wall panels provide flexibility in assembly and disassembly



Figure 6 – Deconstruction of a regular dry wall system

- Walls should be designed to be non-load bearing. A wall should be just a membrane that goes in between the structural system. This will reduce the over all weight of the building and will also facilitate the optimum use of mortar.
- Chemical bonds should be made weaker than the parts being connected. This is so that bonds will break during disassembly rather than the components. Mortar that facilitates the separation of the individual bricks should be used. Meaning, the mortar should be significantly weaker than the bricks. To elucidate this situation let's see small case study of Hume Hall at the University of Florida, Gainesville, USA. The author of this report was involved in a one-day workshop where bricks were being salvaged from the demolished Hume Hall building, a student dormitory at the

University of Florida, to be put in use for Rinker Hall – a new facility for the M.E. Rinker School of Building Construction. It was observed that the bricks that were part of the 100 plus year old building had mortar joints that were extremely strong. This resulted in the breakage of the bricks themselves as the mortar was being cleared. This brings about a question as to, were such strong joints really necessary?

- Provide access to all parts of the building and all components. Ease of access will allow ease of disassembly. It is also preferred that components be recovered from within the building without the use of specialist plant equipment.
- Avoid foam insulations made with HydroChloroFloroCarbon (HCFC).
- Glass curtain walling has both its advantages and drawback. Firstly, it negates the use of masonry walls, which makes the building considerably lighter. This eventually results in less load being transferred to the structural systems and finally to the foundation. But huge glass curtain walling also makes the deconstruction process more difficult as extreme caution has to be taken for its disassembly.
- When designing drywall partitions it is advisable to specify the use of screws or other fasteners instead of nails or adhesives. Nail pulling has always been a time-consuming and expensive activity. In fact, the labor costs of pulling out nails often exceed the market value of the wood, making disposal more economically viable than reuse [1].

Doors & Windows

- Windows and doors must be designed for maximum standardization or repetition. This will facilitate the use of standard dismantling techniques and will also help increase the ‘learning curve’ of the deconstruction labor for that particular building.
- Mechanical connections should always be preferred over chemical ones. This will facilitate easy separation of components and materials without force, and reduce contamination to materials and damage to components.

Roof

- Roof should be designed as composition of assemblies, in which each component can be lowered to the ground individually by means of a crane as an intact unit. This would make the final disassembly process much safer as each of these components can then be dismantled at ground level.
- One of the principles that facilitate deconstruction is the reduced use of chemical sealants in a building. When a building is designed with a flat roof, it demands higher sealant membranes as water gets accumulated in the flat surface and that needs to be drained off mechanically. Instead, if buildings are designed with sloping roofs, water is drained off from the roof automatically by gravity. This results in less reliance on

chemical sealants. But on the other hand, high slope roofs pose a problem for deconstruction working platforms (Figures 7 and 8). This can be avoided by the use of ridge caps that are easily removable and allow access to the roof structure for tie off. Roofs can also be designed to support the requisite load for a worker lifeline. This would facilitate both roof repair and ultimate deconstruction.



Figure 7 – Slope of the roof and workability. Figure 8 – Slope of the roof and workability

- The use of vinyl roofing membranes is a good option to be used in roofing systems. These can be and are being recycled into such second-generation products as speed bumps, parking curbs and asphalt patching material. Nearly all vinyl-roofing manufacturers utilize post-industrial recycled roofing scrap that has been generated in the manufacturing processes of their own products. Steel and wood are typically needed to support heavier roof systems and lightweight vinyl roof systems help reduce the need for these steel and wood members. This in turn means fewer elements to dismantle, which would eventually result in time saved in the deconstruction of the entire structure. Conversely, disposal of a built-up roof could mean high disposal costs, greater material volume in landfills, increased labor requirements and possible exposure to asbestos in the old roofing system [9].

Services

Mechanical, Electrical & Plumbing (MEP) Systems

- The building should be designed in such a manner that it admits sufficient daylight that will naturally illuminate the building interiors as far as possible during the daytime (Figure 9). This will result in less number of light fixtures, which in turn will result in less wiring and less conduits.



Figure 9 – Naturally lit interiors

- Passive solar heating, day lighting and natural cooling can be incorporated to lessen the energy consumption of the building. This will result in lesser units to be used for HVAC.
- In today's high transfer environment, where speed and low signal loss are critical parameters, it is increasingly evident that Category 5 copper wire will be inadequate for most future applications. Fiber optic cable has no such limitations. The average bandwidth for multimode fiber is 500 MHz for one kilometer. In a standard office environment, this would eliminate the need for repeaters and extra closet space. Fiber optic cable does have a premium over copper initially, particularly during installation. But as has been addressed above, the greater transfer rate, permanence and ease of maintenance causes these costs to drop over time. Because fiber is lighter and more flexible than copper, it is also easier to install and remove. Large capacity copper cables require special support structures to handle the weight. This leads to overcrowded chases and conduits eventually taking up a lot of space. Even when the individual cables are not large, the aggregate can be unwieldy and difficult to manage. This ultimately makes the deconstruction process difficult and complicated. A duplex fiber-optic cable weighs 12 lbs. per 1000 feet and is much more flexible. Additionally, the bandwidth is also much larger. Fiber optic cables can be installed in the same conduits as power cables [10].
- Lift shafts are generally made up off concrete shear walls. These play a vital role in the lateral stability of buildings. Knocking out partitions between each lift to make one large lift well would facilitate moving materials down through the building during the deconstruction phase. As lifts are structurally massive these are ideal waste chutes. In confined urban sites where land is at a premium this makes a lot of sense.
- Electrical systems should be designed in such a way that power for the entire building can be turned off conveniently during the deconstruction process.

Space Plan

Finishes

- Use lightweight materials and components; this will make handling easier, quicker, and less costly, thereby making reuse a more attractive option (Figure 10).



Figure 10 – Light-weight materials facilitate easy handling during deconstruction

- Secondary finishes and coatings should be avoided as far as possible. Such coatings may contaminate the base material and make recycling less practical. Where possible, materials that provide their own suitable surface finish should be used. If at all finishes are necessary then, mechanically connected finishes can be used. This is taking into consideration that protective coatings such as galvanizing will still be desirable in some situations for other reasons.
- Avoid vinyl wall coverings.
- One office layer where a more circular approach wherein a material is produced, used, and reused a couple of times till it eventually becomes waste, has begun to happen is the carpet layer. Interface of Atlanta Georgia, USA has been a leading innovator in the carpet sector. According to their research 10 to 20 % of carpets have 80 to 90% of the wear during the course of time. So their new product line includes carpet tiles that have replaced conventional large size carpets. Carpet tiles can be routinely checked and it is also possible to replace the worn carpet tiles of all their customers. This has led to over an 80% saving in materials. Recycling a complex composite material poses a lot of problems; hence, Interface has developed a new polymeric carpet material. This can be remanufactured back into itself, producing almost 100% less waste than normal carpets. This new service and continual recycling approach has resulted in reducing the resources needed to provide carpets by over 30 times [8].
- Design cladding systems that are fixed by snap release connectors, friction, or other joints that do not require sealants.
- It is also advisable to design a building for standard colors and materials. This would lead to waste prevention because typically, when a construction project is completed, extra materials are usually kept for future repairs. Quantities of homogeneous leftovers would be easier to reuse and recycle in the future life cycle of the building.

Interiors

- Partition walls used to separate different activity space should be to the minimum. Especially in cases where the space occupied is to be used for corporate activity, an open office planning should be adopted. Interior design units like storage cabinets can separate areas with different activities that need only a visual barrier. This will reduce the number of partition walls. Creation of levels in the floor can also differentiate various activity areas.
- The building should be designed to incorporate open-ceiling systems in its interiors (Figure 11). This will minimize the materials used and thereby enhance deconstruction.



Figure 11 – Open ceiling system

- As far as possible the layout of the service areas should be such that they are grouped together at one location. This will avoid routing service lines throughout the building. This again will ease the process of deconstruction making it less tedious.

It also can be gathered from the many works of researchers that a good deal of skepticism abounds with respect to the efficacy of the concept of ‘design for deconstruction’. Many practitioners would be sympathetic to the view that such concepts are just passing phases and hence it is paramount to distinguish genuine cultural shifts in the building industry from what can simply be trendy ideas. Sometimes innovation is not a new product or a piece of equipment, but rather a new way of seeing an old problem. By viewing with a new perspective we are able to use existing technology in an entirely different way

CONCLUSIONS

When today’s buildings reach the end of their useful life, the option to demolish and send them to the landfill may no longer exist. Instead, economic and ecological realities may dictate that they be preserved, refurbished, reused, or, when none of those options is possible, that their component materials be salvaged. In such a scenario, buildings designed for disassembly—those made with durable, well-marked materials, minimal toxic constituents, and able to be easily taken apart—will have the greatest value [1].

Environmental degradation and natural resource depletion is unquestionably reaching alarming proportions. Therefore, the concept of design for deconstruction has to be realized at the programming stage. Issues of deconstruction should be included in the risk-assessment guidelines that designers use for advising their clients.

There are four different factors that go into the reuse of materials: technical, environmental, economical, and legal. Almost everything can be pulled apart or dismantled, but the question is will it be economically viable? Or does it reduce the impact on the environment? A building might meet certain regulations and codes in the time when it was built, but when it or the elements will be re-used after 50 odd years, will they meet the standards valid in that period? Design for deconstruction may in the short term have added economic and possibly environmental costs, but on the much larger scale of the life cycle of resources, the long-term benefits are potentially much greater. The future will be different, not necessarily because people decide to behave differently, but because the underlying factors will necessitate change. Design for deconstruction may not always be appropriate, as design for ease of assembly may not be. But in the construction industry, which is responsible for such a large portion of our resource use

and waste production, it is a strategy worthy of exploration.

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