The Transformation of Architecture: Design for Dis-assembly

Matthew Gines- University of New Mexico

Chris Beorkrem- University of North Carolina Charlotte

Abstract

The research presented in this paper focuses on the performance of an architecture responding firstly and primarily to its ecology and available resources; this criteria will change how the design performs throughout its lifecycle. If we as architects intend to use technology to become true 21st century "master builders" we must understand that the term entails a very different set of parameters than it did 500 years ago. The responsibility for the generation of waste has returned to the architect. We propose that this responsibility translates into a design methodology. First, the primary criteria for construction, is the use of a process creating 0% waste. Second, the building must be able to adapt and change, to mature along with its occupants. Thirdly, as a product of the first two criteria, the building must have the ability to be disassembled in part or in whole to be re-assembled, re-used, or re-manufactured.

Performance-based architecture is defined by more than the simple building product. It is composed of a complex set of systems, both technological and cultural, made of physical commodities and human effort. Ultimately, the Architect is responsible for coordinating this discourse; responsible from the point of conception to the destruction of the building. This responsibility includes not only how the building performs throughout its life- cycle, but equally how it performs during construction, through adaptive re-use and in its eventual demolition. We must consider every commodity consumed in the production of building products as a part of its design. The EPA reports 331 million tons[1] of construction and demolition waste and debris was generated in 2008. 60% of all landfill waste is a result of the building industry (not including waste from civil projects such as bridges, roads, subways, or rail systems.)

"We need buildings which fulfill their task today and will do so tomorrow, which in other words, do not age in adhering to their forms and this becomes a drag upon the economy as well as the visual environment. But in order to build adaptably we must try to build as lightly, as movably, as possible and with the greatest perfection technically available." [2]

This paper is the product of a year long thesis project investigating an approach to assembly that will ultimately

---

[1] EPA. *2008 Sector Performance Report*. Rep. 2009. Page 41 Electronic. http://www.epa.gov/ispd/performance.html

[2] "Larsen, Olga Popovic, and Andy Tyas. *Conceptual Structural Design Bridging the Gap Between Architects and Engineers*. Nashville: Thomas Telford, 2003. Print.

allow for a comprehensive consideration of design related to environmental and human health impacts over the life-cycle of a building. The paper will include a survey of historical and contemporary, available and imagined construction methods and processes. It will demonstrate proposals for a variety of new construction methods, which afford the flexibility to design for 0% waste. The work demonstrated will go beyond analysis and attempt to demonstrate methods for combining software and digital manufacturing processes to increase performance and assembly time.

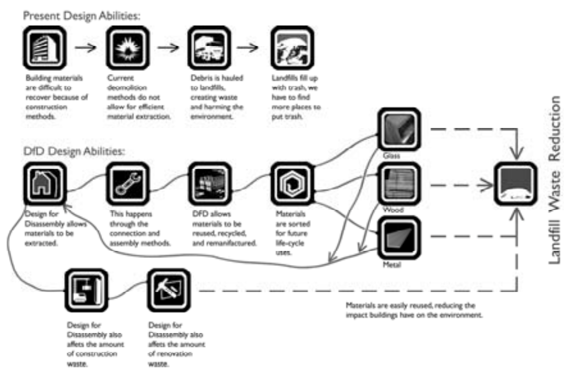
Design for Disassembly is a new method, a re-prioritization of process that considers every day of a buildings life cycle with equal weight.

Moving Beyond Temporality

Buildings are temporary. The responsibility of a generation of architects and engineers dealing with consumption and waste, on a scale unimagined, has begun to shift; the result of this epidemic will be a sea change in construction methods and material usage. It is difficult to determine what the future for any building may hold; to assess the length of time a building will stand, or how human behavior and occupant needs may change its program or define its use. What is apparent is the need for wholesale change, change in the way Architects think, change in the way materials are used and recovered, and change in how buildings are able to perform throughout their lifecycle.

The typical building is a set of predominately rigid pieces constructed in an immovable configuration. Buildings are simply not designed to accommodate change, however they occupy an entropic world, where circumstances always change. Technology, culture, human behavior, and the environment affect the generational shift that happens over time. It is these shifting periods that have distanced the master builder (architect, builder, product engineer, materials scientist) from their trade. As technology and the environment continue to challenge and change what we know, it also provides opportunities to adapt the current methods of design, fabrication, construction and recovery of resources into new models. As time passes, so must conventional design practices, so must a static definition of Architecture.

In order to recover materials and resources we must take a backwards approach to design. *Design for Dis-assembly* is an idea front loaded with responsibility – although the architect may not typically be involved with a building's demolition, the responsibility of a building's afterlife is determined by the construction processes defined in plan and section. The architect is responsible for defining the method of demolition for the buildings they design; – a backhoe and wrecking ball or through dismantling. As designers we must consider how our decisions in the construction process result in a figural "death" and burial in a landfill, or through the process of disassembly, creating the possibility for an "after-life" for the components that once stood together as an assembly.



The Responsibility of Architects and Architecture

As we return to the model of the master builder we must stand up and take responsibility for every aspect of a building. Every commodity consumed in the production of building must be considered as a part of a responsible design process. The EPA reports 331 million tons[3] of construction and demolition waste and debris was generated in 2008. 60% of all landfill waste is a result of the building industry (not including waste from civil projects such as bridges, roads, subways, or rail systems.) This reverse approach to assembly will ultimately allow for a comprehensive consideration of design related to environmental and human health impacts over the life-cycle of a building. We can work to reduce the impacts of typical consumption and landfill processes, but these will have only a minor impact. Similar to the shifts in the automobile industry to hybrids, they provide shifts to more sustainable methods while still operating within the typical carbon-based energy production.

Design for Disassembly, is the only real method of optimization. By considering holistic changes to assembly, componentry, and systems design and establishing a culture of re-usable building components and materials. Design for Disassembly is a method of design that supports future change, it allows buildings to transform and adapt as society and patrons need it to. This method of design simply provides the ability to recover, reuse, rebuild and reconfigure materials.

This backwards view, from end game to construction, will ultimately allow for a comprehensive consideration of design related to environmental and human health impacts over the life cycle of a building. Design for Disassembly, is the method of optimization through; assembly, component connections, and systematic design. Design for Disassembly supports future change; it accommodates people, place and the environment. This method of design simply provides the ability to recover, reuse, rebuild and transform materials and configurations of buildings. This methodology is not a different form of architecture, but a new articulation in the design and construction process.

The list of processes and customs, which must change starts with our expectations for construction processes and personnel. We have long relied on processes tied to a craftsman based assembly process, where a craftsman learns through thousands of hours of apprenticeship. We need to move away from this resource intense process to one of *assembly*. "Assembly differs from construction in that it requires very little skill; it does not rely on information

[3] EPA. *2008 Sector Performance Report*. Rep. 2009. Page 41 Electronic. http://www.epa.gov/ispd/performance.html

passed on through experience or development through apprenticeship. Assembly comes from a hierarchical understanding of groups of assemblies that all connect through series of steps."[4] Assembly allows for rapid production through a specific set of smaller sets of assemblies and connections. By removing the necessity for the craftsman, the architect is again responsible for the precision and quality of their work. Not only does this responsibility free the designer from many of the intense hours of construction administration but it also gives us the sense that we are able to and are responsible for the craft and quality of the construction, something we should all desire.

Digital Building Equals Real Building

These changes are made possible through digital processes in construction and design, because buildings can be explored and built digitally with extreme precision; the designer can work out sets of assemblies and actually simulate the assembly process prior to anything being physically built. The relationship between parametric – building information modeling and an investigation into the opportunity that lie within design for disassembly will inform designers through a set of constraints and conditions derived through an awareness of the environment. Through the simultaneous investigation of connection, assembly, BIM, and product lifecycle, and exploration through analysis will evolve developing a systematic method for assessing levels of prefabrication as well as the necessary level of design for disassembly. These studies will provide, through fabrication, diagrammatic analysis, and parametric systems, a change that will prompt a further investigation of the possibilities and revolution of architecture.

[4] Kieran, Stephen, and James Timberlake. Refabricating Architecture. New York: McGraw-Hill Professional, 2003.

Simulative modeling cannot be comprised of lines that represent parts; it however must be crafted by elements and assemblies of parts. Simulation modeling creates the opportunity for architects to develop a case-by-case kit of parts. Through a simulative model, an architect can choose which components could be pre-assembled, and which should be assembled on site. Manufacturers of materials are also able to produce their parts parametrically with limitations set by the manufacturer. Through parametric modeling, all the information is grounded to one place, one set of systems and are all in unison. All the documents provide the information from the same reference point, creating a system that cannot contradict itself.

The Financial Shift

The architect, and the client, should consider a building as a financier views an investment. A building becomes a vault, a place to deposit their materials and resources. The materials deposited in that location are safe forever, and could stay, make changes or be withdrawn and replaced. Materials stored in a building increase in value as limited worldwide resources decrease and demand increases. Just as demand for the land that a building sits on can increase, so should the value of the materials. As technology continues to expand, a building designed for disassembly will be able to regenerate, renew and update itself through the disassembly and reassembly of particular components. Designing for assembly through the careful consideration for disassembly will make it possible to extract materials when necessary.

The motivation for change has to come from clients, though we as designers must be educators in this sense. Clients have the only financial links to the endgame of the products, which go into a building. As the proportion of property value shifts from primarily land to primarily material this motivation will become more apparent to clients. We must educate clients to consider the materiality of their projects as an investment with a significant return, just as any other commodity based investment would be a part of their portfolio.

We do not propose that we recreate the conventional material palette for designers (though this undoubtedly could assist in minimizing our effect on the environment). The intention is to use standard architectural materials in new assemblies and processes to create components that can be assembled, disassembled, and reassembled in multiple ways. It is the methods of connection that must be re-designed to accommodate standard architectural materials.

We propose that we don't simply think of a single moment of disassembly but that we consider the reality is that most structures need to change and adapt to new and alternative needs and programs. We suggest that we construct using systems, which provide the opportunity for a building to be dismantled (in part or whole) both during and at the end of its lifecycle. Although it can be difficult to anticipate change; change in a city or a building, we can accommodate these changes by providing buildings the ability to quickly adapt. To the client, a building that can perform for them throughout not their life, but instead the life of the building will be more beneficial to them. Through analysis and discussion with the client and patrons of a project it will be possible to assess the life span of each part of a project. Through this analysis designers will be able to use various levels of flexibility in different pieces of a project. It is yet another responsibility of the architect to determine on a case by case basis, what level of disassembly is necessary, whether it be; entire building : interior : structure : façade : or other specific entity.

Industry Precedent

Because there are few examples of these processes in our own industry we must look elsewhere for models of efficiency through assembly. In the early 90's the automotive industry had a similar crisis of quality, construction, and productivity. The solution revolutionized, quality control and speed of production in the automotive industry. Car manufacturers design multiple vehicles on their lines to have interchangeable parts in order to produce fewer parts compatible with more vehicle types. BMW car parts either come from recycled products or the part is able to be recycled back into the pool of useable material. The industry historically produced and assembled each of the approximately 4,000 plus parts in one elongated process. They learned that spreading the assembly process out to approximately fifteen assemblies could create a shorter assembly sequence. By having each larger component arrive at the plant pre-assembled by a separate manufacturer quality control occurs prior to the final assembly, increasing production, innovation and design. Ultimately this revitalization and redesign lowered cost and improved overall quality.

We not only look at the automotive industry, but even at products already used on or in our own buildings. A product referred to as Kee- Klamp, is used on buildings across the world as railings, fall protection, scaffolding and other safety devices. This system uses galvanized pipe to create a wide range of applications. It is not the pipe that is interesting, but the method in which the company has designed and offered over 90 different connectors and fittings. These connectors simply slide on, and tighten to the pipe, allowing the Kee- Klamp system to be configured, and re-configured an infinite number of times. It is necessary to take away from this system, the process of assembly. Because everything must slide on to the pipes at one time it takes more thought in preparation and design so that the designer is sure to have all he connectors not only on the pipe but also in the correct order. So we learn from this system, that a system for architecture may also need to carefully think about its own order of operations.

Much like the vehicle industry, building components could be pre-assembled. What if you could buy wall sections at home depot? Instead of building the typical eight by eight by ten wall system, stick by stick a builder could simply have them delivered to the site in unitized components already assembled and ready for implementation. This idea of pre-assembly versus site assembly is not an entirely new concept, we use this same inherent idea when we use Simpson Ties to pre-build roof trusses, or to lay plywood decking with clips. The amount of research and effort that has gone in to these several hundred connectors is quite amazing, and if we take those same ideas, we learn from them, and we expand upon them, we will be able to create a system capable of dis-assembly, adaptation and change. We already know how to do this in architecture, we simply have not taken it to the next level where we could drastically change the amount of time it takes to erect a building. The prefabrication of components will not only reduce time, but will also reduce environmental waste both on the jobsite and in fuel costs related to the delivery of individual materials.

> "The question for all engaged in design and construction is whether we have the desire, insight, and resourcefulness to seize the challenge that the current crisis affords." - Stephen Kieran[5]

A New Era

Changing the way we look at buildings, and the way in which materials are put in them will provide a more flexible, adaptive infrastructure establishing a new era in reusable architecture. This will result in buildings with an endless lifecycle. Although we as architects may come and go, our decisions while we are here can have lasting impacts, on industry, change, economics, and the environment. Many buildings have and will live for thousands of years others have and will be repurposed as other buildings (roman

---

[5] Kieran, Stephen, and James Timberlake. Refabricating Architecture. New York: McGraw-Hill Professional, 2003.

spolio), and some will be recycled as raw materials. This last option, represents the most flexible and realistic method for diminishing the amount of waste we as designers produce over our careers.

The components used in a design for disassembly process are a symbiotic parasite. They need a host to survive. They have the capability of splitting off from their original host and counterparts in order to take part in multiple projects. Components and materials maybe able to evolve and have an elongated lifeline similar to a person. Materials would be born (milled or manufactured), they would live with their parents (their original building), they could have the potential to move out (renovations), those materials could then find their way in to a new home (a component in a new project), and finally they could be reincarnated (melted down, recycled, remanufactured). However, the difference in a material life cycle and a person is not only the length between events, but also what happens to a material after death. Once a material has “died”, and is no longer usable, it can again have a new life.

The recovery of materials by design for disassembly is intended to maximize economic value and minimize environmental impacts through reuse, repair, remanufacture and recycling. Additionally, we propose to use easily recycled materials, particular strategies for construction can eliminate adhesives and coatings, rendering more products, which can more easily be recycled. For example, wood materials can be turned into mulch or used in new composite materials, and metals can be reprocessed and manufactured in to new building components. Materials broken down to their atomic state can theoretically be reused ad infinitum through re-use or remanufacturing. We can reduce the number of materials, which makes transportation to and from a construction site more efficient. Employing reversible fasteners, screws and bolts as opposed to nails, and using finished parts to ensure their durability and ability to be easily dismantled.

The recyclable building will be able to be assembled, and disassembled in ways allowing materials to be re-assembled, re-used, or repurposed. The recyclable building is imperative to re-establishing a continued existence for our resources and materials. A building that can be disassembled and reused will be instrumental in sustainable architecture and design. The recyclable building will not only change the way we think about materials and resources, but will also create an entire industry built around recycling, sorting, and designing using this theory. Two things are necessary in order to create a constant cycle of reusable materials: re-think the method in which buildings are assembled, and disassemble instead of demolish. The marriage of these two concepts will sustain the building industry and will ultimately take control of the amount of materials that are used and wasted.

Some components will be difficult to recover. It is a given that some material qualities may not be intact and at a certain point some materials do in fact become waste. This is unavoidable. However, there is a large percentage of waste to be collected, calculated and re-used or recycled. This is the target market, the items that can and should be used in a more intelligent manner. Although designers will always be challenging the ways materials are used and their lifecycles it is necessary to focus the concern on the largest and typically most important system: the structure. The structure of a building becomes the most important part for such a system of disassembly and will lead to future development of additional disassemble-able configurations. A structural system designed for disassembly; through the method of assembly; with the lifecycle of the materials as a consideration will be changeable, adaptable and updatable beyond our lifespan. The structural components are the pieces of each structure with the most mass and density, capable of carrying larger loads, and maintaining their consistency over long periods of time. Other materials that are currently completely waste material will also need to be assessed for their value to the project and the planet. For example; drywall, there is virtually no second use for it. Once it is removed it has no chance for recovery or re-application. To address this and other such materials we, as design professionals need to begin to alter application methods, material content, and removal strategies.

The understanding of these theoretical solutions can only come from the direct implementation through a design problem and strategy. Exploring existing systematic structural solutions with disassemble-able properties proposes an intervention in the way buildings are assembled, used, changed, and adapted. We found a series of potential off-the-shelf systems, with particular connection typologies such as; Kee- Klamp®, Simpson Ties®, and Rexroth Bosch Group® provide the flexibility not only in assemblage, but also in design to formulate a systematic configuration of adaptable, changeable, updateable structure. In the exploration of all three systems one particular type of joint appeared as a figural piece. A type of u-joint, similar to that on a car was available in all three structural systems. A universal joint may be an integral part of these systems; it alone, is flexible, changeable and reusable in a number of configurations. These systems would allow a designer, builder or owner to change their building as their needs changed. If their office were expanding, they could purchase additional units to plug-in to their existing frame system, likewise in a downturn the same could be accomplished by selling off components no longer needed.

Architects have been exploring the idea of pre-fabrication, module construction, and a kit of parts approach since the 1950's, however we are finally at a point where technology is advanced enough to support our endeavor. Kieren Timberlake is among the few who have explored this in recent years, and have been successful as a result of technology. Kieren Timberlake did something that we as architects have done for centuries; they saw a product being used in another industry, and experimented with it. Using Rexroth's Bosch extruded aluminum material they first designed and built the Loblolly House; a house mixed of pre-fabrication, on site building, and parts designed to easily go together or come apart. The first issue that arises as a result of this project is the foundation, the piles driven in to the ground is not a precision process, which is contrary to a system that is capable of dis-assembling. Their frame system of disassemble-able aluminum does very little for this project as a whole, it is simply there to slide in the pre-fabricated "units" or "cubes". These cubes are typical of the building industry, constructed of wood and nail, simply in a factory instead of on site. Except for the frame in which these rooms plugged in to this house became another immoveable structure, it is the frame itself that is interesting as a disassembly system. The logic imbedded in Boschs' frame is quite beautiful, the "T" bolt system allows anyone to easily put it together or take it apart. The largest problem with it is that it was not intended to be used in an architectural application. This resulted in the custom design of connective brackets and shear rods. These brackets that actually allow the house to be structural defy the logic of this "T" bolt system. These brackets require holes to be pierced in the aluminum, creating a problematic response for anyone attempting to re-use these parts when the building is dis- assembled. The adaptation of the frame is truly contrary to what a system like this wants to be. The system wants to be pure.

The loblolly house lead Kieren Timberlake to build the Cellophane house; an installation and experimentation at the MoMA: *Home Delivery* exhibition. This house is more successful in its use of the Bosch material as structure and frame, it does not use plug in style wood cubes to define the spaces inside. This system did become more pure, it progressed. Although it progressed and we can learn from this, it still struggles with real issues like insulation, material usage, most important the envelope of the building. The truly unique thing that this building did and is able to do is that it was assembled very quickly, and at the end of the exhibit, or the end of its life, it was taken apart, loaded in a semi trailer, and has the ability to be re-assembled on another site. We learn two important facts; the first is that other industries are far ahead of architecture in their simple logic of construction objects, and the second is that instead of adapting a system to architecture. Architecture must adapt and create its own system.

We can truly begin to control the entire process of both on-site and in factory assembly sequencing by borrowing another type of technology. By using data matrix bar coding we can label or tag every part and piece in our buildings. These data matrix allow each construction crewmember to scan them and access immediately not only the drawing for that item, but also where it is located, what it connects to and when it gets erected. Data Matrix bar codes are an arranged set of nodules arranged inside of a perimeter locator pattern. The data matrix can encode up to 3,116 . The bar codes consist of a hierarchical set of conditions; data regions, which surround nodules, set out in a regular array. Large bar codes can contain several regions. Each se of regional data is delineated by a finder pattern, and this is surrounded on all sides by a blank border. These bar codes are full of several sets of information. This information could be embedded in each piece of material on the job. Instead of retrieving a set of plans and locating each piece it is done very simply through the data matrix code and scanner. This will ultimately allow the assembly of a building to eliminate the time it takes to look at a set of plans and explain where parts and pieces go next. Everything can be controlled down to the sequence of assembly, and the process of documentation.

The building and design industry is not capable of changing and adopting this theoretical appliqué overnight. It will be a slow transition over time through the avenue of technology.

Conclusion

Without a drastic change in the way architecture addresses waste we will ultimately drive our own obsolescence as a profession and as a society. In our lifetimes we will see materials become more scarce and inevitable dramatic price increases. A *Design for Dis- assembly* approach will not only sustain our environmental impact but also the economics tied to material waste. As the profession begins to adapt the way we think, we become responsible. As the profession as a whole becomes more responsible we will see building codes, design guidelines, and LEED organizations not only begin to support the movement, but to make efforts to guide this movement. The effort for this transformation will not just come from the architecture profession, but it will be a result of the entire industry, from building inspectors, to material and product manufacturers who must all be a part of this change. The key to the successful integration is architects, designers, educators and the profession of architecture must become the leader in this movement. It is now clear that we must be the instigators of this change.

Bibliography

1. Falk, Bob, and Brad Guy. Unbuilding : Salvaging the Architectural Treasures of Unwanted Houses. Newtown: Taunton, 2007.
2. Guy, Brad, and Nicholas Ciarimboli. "Design for Disassembly in the Built Environment." Lifecycle building. 2005. 21 July 2008 <http://lifecyclebuilding.org>.
3. Kieran, Stephen, and James Timberlake. Loblolly House : Elements of a New Architecture. New York: Princeton Architectural P, 2008.
4. Kieran, Stephen, and James Timberlake. Refabricating Architecture. New York: McGraw-Hill Professional, 2003.
5. Kronenburg, Robert. Portable Architecture. New York: Architectural P, 2003.
6. McDonough, William, and Michael Braungart. Cradle to Cradle : Remaking the Way We Make Things. New York: North Point P, 2002.
7. Napier, Tom. "Construction Waste Management." Whole Building Design Guide. 15 June 2007. U.S. Army Corps of Engineers. 11 Apr. 2008 <http://www.wbdg.org/resources/cwmgmt.php>.