DECONSTRUCTION’S ROLE IN AN ECOLOGY OF CONSTRUCTION

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SUMMARY

By definition, practitioners of sustainable construction should apply ecological principles to the design and operation of the built environment. Recent work on developing a theory of sustainable construction leans heavily on the inclusion of ecology as the fundamental theory and philosophy for a sustainable built environment. Deconstruction has emerged in the past 5 years as a significant consideration in improving the productivity of materials in construction and is an important step in the practical sense of allowing both effective materials reuse and enhanced recycling. Construction ecology seeks to provide a theoretical basis for understanding the optimal design of the built environment and relies heavily on several branches of ecology, such as systems ecology, adaptive management, and exergy analysis. This paper addresses the role and position of deconstruction in the framework of construction ecology and shows how it plays a key role in insuring optimal and effective use of materials in a construction context. The work of several ecologists and industrial ecologists will be presented and compared with ongoing efforts of deconstruction. Design for deconstruction will be compared to the inherent design of natural systems for effective recycling of the materials that comprise ecological systems. Several basic rules will be presented to better direct the design of buildings in the direction of true ecological design.

KEYWORDS: Deconstruction; Design for the Environment; Industrial Ecology; Construction Ecology; Waste Streams; Supply Chains

CONSTRUCTION INDUSTRY CONSUMPTION AND WASTE

Materials consumption by construction industry dominates worldwide materials consumption. About 40% of all materials extracted annually in the U.S. end up in the built environment [1]. Because construction activity amounts to about 8% of U.S. GDP, the materials impacts of construction far outweigh its relative size in the economy. Materials consumption by construction industry is enormous. In 1993, over 2.1 billion metric tons (BMT) of materials were incorporated into buildings and built environment infrastructure. In 1999, cement consumption in the U.S. was 105 million metric tons (MMT). It has been estimated that over 90% of all the materials ever extracted in the U.S. are in today’s built environment. Consequently policy must address this enormous, burgeoning stock of materials to insure that it becomes, to the greatest degree possible, a resource for future generations rather than an enormous waste disposal problem.

Waste from Construction Activities

Waste from construction activities is also enormous. At present, in the U.S., over 145 MMT of construction and demolition waste are created annually. This is the author’s estimate of 2002 quantities based on the 1998 U.S. Environmental Protection Agency report of about 136 MMT at that time [1]. This compares to a municipal solid waste (MSW) stream of about 280 MMT,
meaning that construction and demolition waste comprises about one-third of the total materials being landfilled. Of the total construction and demolition waste stream, about 92% is attributed to demolition activities and 8% is waste from construction activities, either new buildings or renovation of existing structures. Waste from new construction amounts to 27 Kg/m² while from renovation activities in typical commercial buildings, the quantity of waste can be as much as 320 Kg/m².

The Ecological Rucksack of Construction

Of possibly greater consequence is the Ecological Rucksack of construction or the total quantity of material that must be extracted to obtain a unit of pure material. For example, for iron ore extraction, the Ecological Rucksack can be expressed as the ratio 14:1, that is, 14 metric tons of waste in the form of tailings or mine waste is the result of producing 1 metric ton of iron. For rarer materials, such as gold and platinum, the ratio can range up to 350,000:1. For the most massive quantities of materials used in the built environment, sand, gravel, and stone, the Rucksack is not so unfortunate with a ratio of 1:0.86 for gravel and 1:1.2 for natural stone. Coal extraction’s ratio is 1:5 while that for petroleum is 1:0.1. In addition to the Ecological Rucksacks, the relative scales of extraction need to be considered. For the materials mentioned here, 10 BMT of sand and gravel, 5 BMT of stone, 5 BMT of coal, 5 BMT of petroleum, 0.5 BMT of iron, and 0.0001 BMT of gold were extracted worldwide in 1994 (see Table 1) [2].

<table>
<thead>
<tr>
<th>Material</th>
<th>Ecological Rucksack</th>
<th>Scale (BMT)</th>
</tr>
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<tbody>
<tr>
<td>Oil</td>
<td>1:0.1</td>
<td>5</td>
</tr>
<tr>
<td>Sand/Gravel</td>
<td>1:0.86</td>
<td>10</td>
</tr>
<tr>
<td>Natural Stone</td>
<td>1:1.2</td>
<td>5</td>
</tr>
<tr>
<td>Coal</td>
<td>1:5</td>
<td>5</td>
</tr>
<tr>
<td>Gold</td>
<td>1:350 000</td>
<td>0.0001</td>
</tr>
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Table 1 Ecological Rucksack and scale of selected materials

Although Life Cycle Assessment (LCA) of products is being used to sort out the impacts or materials and products, issues such as the Ecological Rucksack tend to be forgotten in spite of the increasing consequences as resources, particularly fossil fuels and metals, become scarcer and more dilute. Deconstruction, which seeks to maximize the productive use of materials by enhancing reuse and recycling, would be a strategy that could directly and dramatically reduce the Ecological Rucksack of construction. This is an important step forward in the overall process of reducing waste and the consequences of creating ever more built environment for a burgeoning world population.

BUILDING SPECIFIC MATERIALS ISSUES

Buildings, the most significant components of the built environment, are complex systems that are perhaps the most significant embodiment of human culture, often lasting over time measured in centuries. Architecture can be a form of high art and great buildings receive much the same
attention and adoration as sculpture and painting. Their designers are revered and criticized in much the same manner as artists. This character of buildings as more than mere industrial products differentiates them from most other artifacts. Their ecology and metabolism is marked by a long lifetime, with large quantities of resources expended in their creation and significant resources consumed over their operational lives.

**Built Environment Effects**

The main purpose of the built environment is to separate humans from natural systems by providing protection from the elements and from physical danger. Modern buildings have increased the sense of separation from the natural climatic processes and have made the underlying biological and chemical processes of nature irrelevant for their occupants. Until humans achieved space travel, the extraction and conversion of materials for building construction has been the highest expression of dominance over the constraints of natural bioclimatic and material constraints. This “constructed” ecology has in turn created an ecological illiteracy and had profound psychological and human health impacts [2]. Concentrations of buildings effect micro-climate (heat islands), hydrology (runoff), soils and plants (suffocation and compression), and create false natural habitats (nests on buildings). This increasing separation of ecological feedback loops inherent in the design, construction and use of buildings since the Industrial Revolution has brought many architects back to an era of reconsideration of this de-evolutionary and unsustainable path. The construction industry is extremely conservative and subject to slow rates of change due to regulatory, liability, and limited technology transfer from other sectors of society. 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. Modern buildings, although products of industrial societies, are perhaps unique among modern technologies in terms of the diversity of components, unlimited forms and content, waste during the production process, land requirements, and long term environmental impacts.

Buildings as artifacts of human society are also distinguished to a large extent by their relatively large land requirements and the environmental effects of the cooption of this valuable ecological resource. The built environment significantly modifies natural hydrologic cycles, contributes enormously to global environmental change, has tremendous effects on biodiversity, contributes to soil erosion, has major negative effects on water and air quality, and, as noted above, is the source of major quantities of solid waste. In the U.S., as noted earlier, construction and demolition waste is the major source of industrial waste, amounting to perhaps 500 Kg per capita or on the order of 145 MMT annually. In the U.S. the reuse and recycling rates of this waste is not well known but is probably under 20% of the total mass and probably closer to 10%. Only concrete recycled for its aggregates and metals are recycled at high rates because of their relatively high economic value.

The built environment interacts with the natural environment at a variety of scales, from individual structures affecting their local environment to cities impacting the regional environment, affecting weather by changing the Earth’s albedo [1] and other surface
characteristics, altering natural hydrological cycles, and degrading air, water, and land via the emissions of its energy systems and due to the behavior of its inhabitants.

Classifying Building Products

Buildings can be distinguished from other artifacts by their individuality and the wide variety of constituent parts. Buildings are assembled from a wide array of components that can be generally divided into 5 general categories:

1. Manufactured, site-installed commodity products, systems, and components with little or no site processing (boilers, valves, electrical transformers, doors, windows, lighting, bricks);
2. Engineered, off-site fabricated, site-assembled components (structural steel, precast concrete elements, glulam beams, engineered wood products, wood or metal trusses);
3. Off-site processed, site-finished products (cast-in-place concrete, asphalt, aggregates, soil);
4. Manufactured, site-processed products (dimensional lumber, drywall, plywood, electrical wiring, insulation, metal and plastic piping, ductwork);
5. Manufactured, site-installed, low mass products (paints, sealers, varnishes, glues, mastics).

Each of these categories of building components has an influence on the potential for reuse or recycling at the end of the building’s useful life and the quantity of waste generated during site assembly. Category 1 components, because they are manufactured as complete systems, can be more easily designed for remanufacturing, reuse, and disassembly, and thus have a excellent potential for being placed into a closed materials loop. Category 2 products also have this potential although engineered wood products, a relatively new technology, have not been scrutinized as to their fate. Concrete products fit into the first 3 categories and the extraction of aggregates for further use is technically and, in many cases, economically feasible. Category 4 products are in some cases more difficult to reuse or recycle, although metals in general are recycled at a very high rate in most countries. Category 5 products are virtually impossible to recycle and in many cases are sources of contamination for other categories of products, making their recycling very difficult.

Construction industry also differs from other industrial sectors in that the end products, buildings, are not factory produced with high tolerances, but are generally once-off products designed to relatively low tolerances by widely varying teams of architects and engineers, and assembled at the site using significant quantities of labor from a wide array of subcontractors and craftspeople. The end products or buildings are generally not subject to extensive quality checks and testing and they are not generally identified with their producers, unlike, for example, automobiles or refrigerators. Unlike the implementation of Extended Producer Responsibility (EPR) in the German automobile industry which is resulting in near closed loop behavior for that industry, buildings are far less likely to have their components returned to their original producers for take-back at the end of their life cycle. Arguably EPR could be applied to components that are routinely replaced during the building life cycle and that are readily able to be decoupled from the building structure (chillers, plumbing fixtures, elevators). The bulk of a building’s mass is not easily disassembled and at present there is little thought given in the design process to the fate of building materials at the end of the structure’s useful life.
Building and Building Component Service Life

Most industrial products have an associated lifetime that is a function of their design, the materials comprising them, and the character of their service life. The design life of buildings in the developed world is typically specified in the range of 30 to 100 years. However, the service lives of buildings are unpredictable because the major component parts of the built environment wear out at different rates, complicating replacement and repair schedules. Stewart Brand [5] describes these variable decay rates as “shearing layers of change” that create a constant temporal tension in buildings. Brand adapted O’Neill’s [6] hierarchical model of ecosystems to illustrate the issue of temporal hierarchy in buildings that can be related to the spatial decoupling of components (See Figure 1). Faster cycling components such as Space Plan elements are in conflict with slower materials such as Structure and Site. Management of a building’s temporal tension might be achieved with more efficient use of materials through spatial decoupling of slow and fast components. Components with faster replacement cycles would be more readily accessible. This hierarchy is also a hierarchy of control, i.e. the slower components will control the faster components. However, when the physical or technical degradation of faster components surpasses critical thresholds, they begin to drive changes to the slower components such that dynamic structural change can occur. For example, in a typical office building, electrical and electronic components wear out or become obsolete at a fairly high rate compared to the long-lived building structure. At some critical threshold the motivation to maintain the overall building ebbs and the building rapidly falls into disuse and disrepair due simply to the degradation of the faster, more technology dependent components. H.T. Odum [7] developed the concept of EMERGY, the energy embodied in the creation and maintenance of a factor or process, as a means to quantify the relative contributions of different components to the operation of a hierarchy. Odum’s theory predicts that the control of faster components by slower components is reflected in the latter’s higher EMERGY transformity values. Transformity values are efficiency ratios of total EMERGY to actual energy, normalized in solar equivalent joules, that enumerate a process’s relative capacity to influence system behavior. Using EMERGY to more carefully distinguish between slower and faster components and processes would allow designers to more rationally couple buildings to external processes of manufacture, reuse, and recycling. As such this theory provides a quantitative framework for relating building design to its material components based on their relative contributions to the functions of an ‘ecosystem’ that includes the built environment and the materials and processes that sustain it.
Understanding component service life and the interaction of the various shearing layers of change should lead to different thinking about buildings with respect to both the products that comprise buildings and the assembly of products into buildings. In discussing deconstruction and the design for deconstruction, the varying rates of change of building components and the issues of how best to separate these layers for ease of replacement are of paramount importance.

**APPROACHES TO CREATING A SUSTAINABLE MATERIALS INDUSTRY**

There are a number of potential approaches for creating a system of sustainable materials use. Several recent attempts have been made to articulate principles or rules that can help direct not only sustainability, but ultimately policy. Several of these are described in the following paragraphs.

**Golden Rules of Eco-Design**

Stefan Bringezu [8] of the Wuppertal Institute suggests what he terms the Golden Rules of Eco-Design:

1. Potential impacts to the environment should be considered on a life cycle-wide basis.
2. Intensity of use of processes, products and services should be maximized.
3. Intensity of resource use (material, energy, and land) should be minimized.
4. Hazardous substances should be eliminated.
5. Resource inputs should be shifted towards renewables

These rules are based on several management rules for sustainability. First, the use of renewable resources should not exceed their regeneration rate. Second, non-renewable resources should only be used if physical and function equivalents are provided such as investing in solar-derived energy from the profits of fossil fuel consumption. Third, the quantity of waste released must not exceed the absorptive capacity of nature. Finally there must ultimately be a balance between
materials inflows and outflows to/from the economy because physical development cannot continue indefinitely and without bound.

Bringezu also suggests that there are four basic construction activities that must be kept in mind to examine materials impacts on a life cycle basis: (1) Design of construction products and buildings; (2) Materials management; (3) Planning of infrastructure; and (4) Product, facility, and building management.

In effect most of these Rules are being implemented in this new era of green building. Life Cycle Assessment (LCA) of products is becoming more widespread, buildings are being designed to more adaptable and materials more durable, and the emphasis is on shifting away from hazardous materials and non-renewables to renewable and recyclable resources. For all practical purposes we do know how to implement the Golden Rules although the meaning of ‘maximize’ and ‘minimize’ in two of the Rules is very much subject to interpretation.

**General Rules of the Production-Consumption System**

James Kay, an ecologist at the University of Waterloo in Ontario, Canada, suggests that the human means of producing artifacts for use or ‘consumption’, should respect a set of rules that recognize the capacity and limits of natural systems [9]. A brief description of these rules is as follows:

1. The interface between man-made systems and natural ecosystems should address the limited ability of natural ecosystems to provide energy and absorb waste before their survival potential is significantly altered. Additionally, the survival potential of natural ecosystems must be maintained. This is referred to as the problem of **interfacing**.

2. The behavior and structure of large scale man-made systems should be as similar as possible to those exhibited by natural ecosystems. This is referred as the **principle of bionics**.

3. Whenever feasible the function of a component of a man-made system should be carried out by a subsystem of the natural biosphere. This is referred to as using **appropriate biotechnology**.

4. Non-renewable resources should be used only as capital expenditures to bring renewable resources on line.

These Rules are far more difficult to implement than the Golden Rules of Eco-Design, largely because the scale of these rules is generally very large, focusing on very large systems such as bioregions. In southern Florida, for example, it is thought that much of the movement and storage of stormwater could be accomplished by creating appropriate interfaces with the watersheds, swamps, rivers, and lakes of the region, rather than creating numerous, expensive manmade stormwater conveyance and storage systems for individual developments and even buildings. This is clearly a win-win set of rules is they can be implemented because the result is the replacement of complex, costly human designed and produced systems with their natural system counterparts.
Industrial Ecology Strategy

Fritz Balkau [10] suggests that industrial ecology can be used as a framework for developing appropriate policies with respect to sustainable materials use. He focuses on implementing and operationalizing industrial ecology through management and policy instruments. In reviewing the concept of Industrial Ecology, he suggests that it might be defined as the study of materials and energy flows, population dynamics, and the operational rules and interrelationships of the entire production system. The challenges in implementing this strategy are insuring the Industrial Ecology concept is complete so that it addresses all policy areas and that an effective combination of management instruments is available for applying the concept in real situations. The main elements of Industrial Ecology that have been suggested are industrial metabolism, industrial ecosystems or associations, materials cycles in nature and industry, and the evolution of industrial technologies. These in turn have resulted in a number of concepts for operationalizing sustainability: the precautionary principles, the prevention principle (cleaner production and eco-efficiency) life-cycle management, the zero emissions concept, dematerialization (the factor 10 concept), and integrated environmental management systems. He suggests that we have not yet seen a mature industrial ecosystem where management systems have evolved sufficiently to produce a true artificial ecology. However a number of management elements have appeared which give us hints at how these management systems may eventually appear. Among the existing dynamic management elements are corporate decisions on sustainability; the adoption of environmental management systems (EMS); the practice of supply chain management; central infrastructure management; cooperative environmental programs; and government industrial development policy. The challenge is to combine these management instruments in an intelligent and systematic fashion.

Balkau suggests that the construction sector also needs to stay abreast of emerging environmental problems and adapt the design, operation, and disposal of the built environment to address new issues. The construction industry also needs to be more aware of the secondary impacts of its activities, that is, the damage done during the extraction of the resources needed for creating the products that comprise buildings and infrastructure. Quality of life as affected by construction also needs to be included in the array of issues for industry awareness and possible action. For example, congested transportation systems, increased noise, and increased municipal solid waste are also outcomes of construction activity. He concludes by suggesting a management framework for Construction Ecology. A wide variety of instruments from environmental standards to building codes and financial criteria can be applied to Construction Ecology and assist its implementation. However the primary prerequisite for creating a framework of management instruments is the definition of environmental goals. To accomplish this, construction industry itself must come up with a common view of its environmental agenda to include parameters such as energy efficiency.

The final lesson provided by the Industrial Ecologists is that implementation of both Industrial Ecology and Construction Ecology must be carried out using the appropriate policy instruments by a variety of entities to include government, corporations, and developers. An environmental agenda that construction industry can agree to is particularly important as it would set the parameters for behavior of the many actors in the construction process. Coordination in the application of policy instruments such as building codes and standards for building products
would help orchestrate a steady march toward a system of creating the built environment that pays careful attention to resource and environmental issues. Coherent action is important to be able to produce change and the establishment of an agenda to integrate policy and technical issues is needed to create this coherency.

**DESIGN FOR THE ENVIRONMENT AND DECONSTRUCTION**

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. Industrial Ecology and Design for the Environment are two of the leading efforts in this movement. Industrial Ecology can be defined as the application of ecological theory to industrial systems or the ecological restructuring of industry. In its implementation it addresses materials, institutional barriers, and regional strategies and experiments. One major direction of Industrial Ecology is the optimization of materials flows by increasing resource productivity or dematerialization. The notion of a service economy, alternatively referred to as ‘systemic dematerialization,’ which sells services instead of the actual material products, is considered the sine qua non of this strategy.

An emerging discipline, Design for the Environment [DFE] has as its goal the creation of artifacts that are environmentally responsible. DFE can be defined as a practice by which environmental considerations are integrated into product and process engineering procedures and that considers the entire product life. This proactive approach to creating artifacts that can be readily adapted, removed, reprocessed, recycled and reused, embodies the concept of “front-loaded” design. Front-loaded design is simply insuring the end-of-life fate of artifacts is not waste but other artifacts. Applying Industrial Ecology and DFE to buildings is the cornerstone of Construction Ecology. Relative to buildings, Industrial Ecology underpins Construction Ecology by providing a framework for the construction materials and products industry to follow to place its activities on a sustainable path. As products of service, all building components could be leased to the owners and be returned to their manufacturers when obsolete, worn-out, or needing replacement. Architects and engineers would design buildings with decoupled systems that allow ready removal at periodic intervals and for large scale deconstruction when necessary for economic or planning purposes.

Efforts to change the close the materials cycle in construction are hampered by many of the same problems facing other industries. The individuality and long life of buildings poses some additional obstacles. Three fundamental difficulties arise when considering closed loop materials cycles for buildings:

1. Buildings are not currently designed or built to be eventually disassembled.

2. Products comprising the built environment are not designed for disassembly.

3. The materials comprising building products are often composites that make recycling extremely difficult.
Clearly a new concept for materials and energy use in construction industry is needed if sustainability is to be achieved. As noted at the start of this chapter, industrial systems in general are beginning to take the first steps toward examining their resource utilization or metabolism, and beginning the process of defining and implementing Industrial Ecology. In this same spirit, a subset of these efforts for construction industry, Construction Ecology, would help accelerate the move toward integrating in with nature and behaving in a ‘natural’ manner. Construction Ecology should consider the development and maintenance of a built environment (1) with a materials system that functions in a closed loop and is integrated with eco-industrial and natural systems; (2) that depends solely on renewable energy sources, and (3) that fosters preservation of natural system functions. Construction Metabolism is resource utilization in the built environment that mimics natural system metabolism by recycling materials resources and by employing renewable energy systems. It would be a result of applying the general principles of Industrial Ecology and the specific dictates of Construction Ecology.

The outcomes of applying these natural system analogues to construction would be a built environment (1) that is readily deconstructable at the end of its useful life; (2) whose components are decoupled from the building for easy replacement; (3) comprised of products that are themselves designed for recycling; (4) whose bulk structural materials are recyclable; (5) whose metabolism would be very slow due to its durability and adaptability; and (6) that promotes health for its human occupants.

As its primary purpose, deconstruction seeks to maintain the highest possible value for materials in existing buildings by dismantling buildings in a manner that will allow the reuse or efficient recycling of the materials that comprise the structure. Deconstruction is emerging as an alternative to demolition around the world. Generally the main problem facing deconstruction today is the fact that architects and builders of the past visualized their creations as being permanent and did not make provisions for their future disassembly. Consequently techniques and tools for dismantling existing structures are under development, research to support deconstruction is ongoing at institutions around the world, and government policy is beginning to address the advantages of deconstruction by increasing disposal costs or in some cases, forbidding the disposal of otherwise useful materials. Designing buildings to build in ease of future deconstruction is beginning to receive attention and architects and other designers are starting to consider this factor for new buildings.

CONCLUSIONS

A new concept for materials and energy use in construction industry is needed if sustainability is to be achieved. Construction Ecology can be considered as the development and maintenance of a built environment [1] with a materials system that functions in a closed loop and is integrated with eco-industrial and natural systems; [2] that depends solely on renewable and recyclable materials, and [3] that fosters preservation of natural system functions. A key element of construction ecology must be deconstruction and, more importantly, design for deconstruction, which creates the conditions for enabling materials to remain in productive use. By designing both building products and buildings for deconstructability, architects and other designers are enabling the extraction of high value materials for reuse and recycling. In closing it is important
to note that it is of the utmost importance that materials having secondary value be used in buildings.

RECOMMENDATIONS

Materials that have no further possibility for reuse and recycling need to be reconsidered for their use in buildings, and for that matter, in all industrial products. This implies the wholesale reexamination and probable redesign of virtually every artifact. Materials used in construction and all other industrial sectors need to be kept in productive use and their reuse and recycling should be maximized. Deconstruction provides the best hope for the construction sector for recycling and reusing materials and components of buildings in future applications. Deconstruction, coupled with products ‘designed for the environment’ and appropriate integrated national and international policies give the best hope for attaining sustainability in the sense of sustainable construction.

REFERENCES


