Deconstruction: the start of a sustainable materials strategy for the built environment

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Summary
Disposal of buildings in most industrial and emerging industrial countries is wasteful and problematic. Waste from building demolition (partial demolition for renovation, or total demolition for building removal) represents 30-50% of total waste in most of these countries. Deconstruction is an alternative to demolition. It calls for buildings to be dismantled or disassembled, and for the components to be reused or recycled. A number of economic and social benefits can be realized by shifting towards better materials recovery practices in the construction sector. Deconstruction preserves the invested embodied energy of materials, thus reducing inputs of new embodied energy during materials reprocessing or remanufacturing. The concept of design for disassembly (DfD) of buildings emerged in the early 1990s. Closing construction materials loops will require including both product design and deconstruction in a process that might be called "design for deconstruction and disassembly" (DfDD).

Résumé
Dans la plupart des pays industriels ou émergents, le démantèlement des bâtiments est une source de gaspillage et de problèmes. Les déchets de démolition (qu’ils s’agissent de démolition partielle avant rénovation ou de démolition totale et définitive) représentent 30 à 50 % du volume global des déchets dans la plupart de ces pays. Or, il existe une alternative à la démolition : "la déconstruction " . Elle consiste à démonter les bâtiments et à réutiliser ou recycler leurs différents éléments. L’adoption de meilleures pratiques de valorisation des matériaux dans le secteur du bâtiment présente un certain nombre d’avantages économiques et sociaux. La " déconstruction " préserve le contenu énergétique des matériaux, réduisant ainsi l’apport de nouveau contenu énergétique lors du retraitement ou du reconditionnement des matériau. Le concept de bâtiments conçus pour leur démolition a été introduit au début des années 1990. Pour pouvoir boucler la boucle des matériaux de construction, il faut intégrer la conception des produits et son démantèlement au sein d’un processus que l’on pourrait qualifier de “ conception pour la déconstruction et le démantèlement " .

Resumen
La supresión de edificios en la mayoría de los países industriales e industriales emergentes genera desechos y problemas. Los desechos de la demolición de edificios (demolición parcial para renovación o demolición total para remover el edificio) representan 30 a 50% del total de desechos en la mayoría de estos países. La deconstrucción es una alternativa a la demolición. Para ello, los edificios deben ser desmantelados o desarmados y sus componentes reutilizados o reciclados. Se pueden obtener beneficios sociales y económicos adoptando mejores prácticas de recuperación de materiales en el sector de la construcción. La deconstrucción preserva la energía invertida e incorporada en los materiales reduciendo así la introducción de nueva energía incorporada al procesar o manufacturar nuevamente los materiales. El concepto de "diseñar edificios para su desmantelamiento" surgió a principio de los años 1990. Para lograr cerrar el ciclo de los materiales de construcción será necesario incluir el diseño y la deconstrucción del producto en un proceso que podría llamarse "diseñar para la deconstrucción y el desmantelamiento".

The materials behaviour of the construction sector of the economy must be characterized as poor during all phases of the building materials cycle - from extraction to construction to final disposal of buildings at the end of their useful lives. Changing this situation will be quite difficult. However, the first steps in the process are under way in at least a dozen countries worldwide. Buildings are being disassembled rather than demolished, and building components and materials are being recovered or recycled for reuse in existing or new buildings. In the Netherlands, for example, at least a dozen different precast reinforced concrete systems have been developed to allow buildings to be disassembled, moved and reconfigured. One of these is the MXB-5 dry-assemble system, in which columns with steel plates at each end are connected to floor elements that have anchor bushings embedded in the concrete. The elements can be connected simply by tightening the connecting bolts. Serious efforts are also being made in several other countries to design buildings for eventual deconstruction.

Initial economic analysis indicates that resale of valuable recovered materials can far offset the additional labour costs associated with building dismantling. New industries to disassemble buildings, process used building components, and resell components and recovered materials can result from implementing deconstruction practices on a large scale. These outcomes make deconstruction an approach well worth considering for countries in which there is significant waste from demolition activities, as well as from natural hazards such as earthquakes and hurricanes.

Deconstruction has several advantages over conventional demolition. It also faces several challenges. Some of the advantages are:
- an increased rate of diversion of demolition waste from landfills;
- potential reuse of building components;
- increased ease of materials recycling;
- enhanced environmental protection, both locally and globally.

Deconstruction preserves the invested embodied energy of materials, thus reducing the input of new embodied energy in reprocessing or remanufacturing materials. A significant reduction of landfill space can also be a consequence. In the United States, where construction and demolition waste represents about one-third of the total volume of materials entering landfills, diversion rate of 80% is being experienced for deconstructed buildings. In the Netherlands increasingly scarce land is being preserved for other uses. In some countries, businesses have developed the technology and techniques to turn former demolition debris into useful aggregate. The clean, sized aggregate in the photo on the next page is processed concrete, masonry and ceramic waste that can be used as a partial aggregate replacement in new concrete or for road sub-base.

The challenges faced by deconstruction are significant, but they can readily be overcome if changes in design and policy occur. They include:
- Existing buildings have not been designed for dismantling;
- Building components have not been designed for disassembly;
- Tools for deconstructing existing buildings often do not exist;
- Disposal costs for demolition waste are frequently low;
- Disposal buildings require additional time;
- Re-certification of used components is not often possible;
- Building codes often do not address the reuse of building components;
- Economic and environmental benefits are not
well established.

These challenges generally fit into the categories of design or policy.

Changing attitudes to building reuse and disposal can increase the materials recycling rate from 10-20% of materials removed from the built environment each year to the 60-70% range and cut demolition waste in half. This can be accomplished by:

- designing building products that can be disassembled and recycled;
- designing buildings that can be deconstructed at times of major renovation and at the end of their useful lives;
- providing incentives for building reuse instead of new building.

The economic and environmental benefits of success would be profound, providing a potentially cheap source of high-quality materials for building products and enormously reducing materials extraction. In an environmental sense, success in closing materials loops even partially in the construction industry would have benefits an order of magnitude or more greater than in any other industry due to the sheer scale of its materials consumption.

Materials flows in the construction sector

Flows of construction materials dominate materials flows in most economies. In the United States, as of November 2002, the annualized value of construction was US$ 843 billion. In an economy of about US$ 10 trillion, the construction industry represents about 8.4% of GDP. When the building product sector is included, an additional estimated US$ 400 billion of GDP can be attributed to construction — a total of US$ 1.2 trillion, or about 12% of GDP.

The materials and waste impacts of these activities are even more significant. The construction sector uses more materials than any other industrial sector by far. Of the 1.9 billion metric tonnes that ended up as domestic stocks in 1996, about 1.6 billion metric tonnes became part of buildings or infrastructure. Extrapolating back up the supply chain, and noting the factor of 8 relationship between total materials extracted and the resulting domestic stocks, it is probable that 13-14 billion metric tonnes of total domestic output was associated with building construction.

With respect to domestic stocks, that is, materials that end up in the economy in some fashion, buildings differ significantly from durable goods. Buildings are unique industrial products compared to other human artifacts due to their individuality, longevity and method of assembly. Unfortunately, it is these same characteristics of buildings that make their materials cycle performance very poor. Buildings and their components, building products, have not historically been designed to be recycled or reused, much less disassembled. The building, which represents the “macro” scale of the problem, is assembled from building products using mechanical, thermal and chemical fastening methods and techniques. The products, representing the “meso” scale of the materials cycle, are assembled without regard to their fate. Most are composite materials that are challenging if not impossible to disassemble. The materials used in building products (the “micro” level) are selected for their performance but also for least cost.

Building materials are overwhelmingly the largest constituent of net additions to the domestic stock in most countries. In the US durable goods such as cars, electronic goods and household appliances account for, at most, 1-2 metric tonnes per capita of materials added to stock each year, while the built environment contributes perhaps as much as 20 metric tonnes of stock per capita each year. The decision whether to shift to deconstruction is a very important national consideration, given the huge quantities of materials involved.

The residence time or useful lifetime of construction materials is long compared to the relatively short residence time of other durable goods. Buildings undergo major renovations on 20-year cycles (about the outer limit of the lifetime of automobiles). They can have useful lives of several hundred years. Even in mature industrial economies with significant road, rail and housing infrastructure, there is not yet any sign of significant reductions in the quantities of new construction materials required each year. Annual enlargements of stock of materials have remained remarkably constant over the past 25 years, rising broadly in line with population growth. These small increases are due to growing demand for transport infrastructure, and to the demand for new housing associated with changing demographic structures and affluence. For example, the number of households is increasing faster than population, as more people live alone or in smaller family groupings. Increasing affluence has encouraged a taste for very large, low-density residences. If this trend continues, many millions of tonnes of minerals will continue to be extracted from the land for the foreseeable future. The most damaging aspects of this trend will be the ongoing loss of productive land, degradation of scenic beauty, fragmentation and disturbance of habitats, and increased pressure on biodiversity.

A variety of economic, technological and cultural factors affect the flow of construction materials. When tracked over time, net additions to stock closely follow economic cycles. Recessions, bull markets, levels of public investment and major construction programmes affect construction materials flows. National building standards and traditions also appear to influence...
Sustainable building and construction

Demolition of Hume Hall, University of Florida, demonstrates a lack of capacity for recovering potentially valuable brick due to inadequate foresight in design and planning.

Progress in deconstruction of one of several 100-year-old houses in Portland, Oregon, by a non-profit company.

 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 at around 50 to 100 years. However, the service lives of buildings are unpredictable because the major components of the built environment wear out at different rates, complicating replacement and repair schedules. These variable decay rates have been referred to as "shearing layers of change", which create a constant temporal tension in buildings. Faster-cycling components, such as elements comprising the space plan, are in conflict with "slower materials" such as the structure and the site. For example, electrical and electronic components in a typical office building wear out or become obsolete at a fairly high rate compared with 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 simply due to the degradation of the faster, more technology dependent components.

A new paradigm: design for deconstruction and disassembly

It is clear that the current state of construction is wasteful and will be difficult to change. Of all the issues facing the rapidly growing high-performance green building movement, the choice of building materials and products is by far the most difficult. Criteria for materials and products for the built environment should be similar to those for industrial products in general. Many materials used in buildings are the same as those used in other industries, most notably metals. But buildings have a distinct character compared to other industrial products. The major differences that make the closing of materials loops in this segment of the economy particularly difficult are indicated in Table 1. The vision of a closed loop system for the construction industry is, of course, one that is integrated with other industries to the maximum extent possible. Many materials, such as metals, can flow back and forth for numerous uses. Others, such as aggregates and gypsum drywall, are unique to construction and their reuse or recycling would stay within construction. Closing materials loops for the built environment will be significantly more difficult due to the factors that make its materials cycles differ significantly from those of other industries.

The notion of design for disassembly (DfD) of buildings emerged in the early 1990s. DfD must be considered at the design stage to be effective. It has also been noted that DfD can reduce long-term waste generation. Experiments conducted with DfD conducted at Robert Gordon University in Aberdeen, Scotland, included a wide range of issues that were considered to facilitate a greatly improved materials cycle handling, materials identification, simplicity of construction techniques, exposure or mechanical connections, independence of structure and partitioning, and making short life-cycle components most accessible.

Research indicates that DfD must consider three levels of the entire materials system in buildings to produce sound product design and construction strategies: systems level, product level, and materials level. Several DfD examples do exist that test various ideas that are part of this concept. A multi-storey residential housing project in Osaka, Japan, uses a reinforced concrete frame to support independently constructed dwellings that can be replaced without removing the supporting
Developing country issues
Perhaps surprisingly, developing countries are in a sense better equipped to deal with deconstruction and materials reuse compared with developed countries. These countries tend to use local materials and vernacular architecture, often creating buildings with the inherent capacity to be dismantled and the components reused. For example, use of timber from sustainably managed forests is another effective use of materials in that these forests are protected to the maximum extent possible and the wood can easily be extracted and reused when the building’s useful life has been reached. Agenda 21 for Construction in Developing Countries provides a detailed framework for considering deconstruction and other sustainable measures for the construction industries of developing countries. It points out that use of traditional measures and building can be a starting point for research into sustainable technologies. Consequently, the experience of developing countries can serve as valuable input for developed countries as they seek to redesign buildings to accommodate deconstruction and materials reuse. Developed countries will have to consider the techniques and materials being used in developing countries in order to successfully close materials loops in their construction industries.

Lack of modern construction materials in developing countries forces innovation. One major success story in developing country sustainable construction efforts is the development of modern versions of earth block. The employment of earth block, made from local soils and sometimes with a relatively small amount of cement as a binder, has been a highly successful enterprise in several developing countries. The New Gourna mosque in Luxor, Egypt, was built with sun dried earth blocks. Several pilot projects in South Africa have used earth block made with simple machinery that can use human or motor power to produce high-quality, stabilized earth block. Both traditional houses and modern houses are being built from earth blocks in South Africa. This “technology” is attracting significant attention from developed country sustainable building movements, which are attempting to find more natural, ecologically friendly building materials and methods.

Policy implications
National and local government policy can contribute to the implementation of deconstruction as standard practice. Economic instruments are by far the easiest means of fostering the improved materials practice of disassem-

Table 2
Principles of design for disassembly (DFD) as applied to buildings

<table>
<thead>
<tr>
<th>Principle</th>
<th>Description</th>
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<tbody>
<tr>
<td>1.</td>
<td>Use recycled and recyclable materials</td>
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<tr>
<td>2.</td>
<td>Minimize the number of types of materials</td>
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<td>3.</td>
<td>Avoid toxic and hazardous materials</td>
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<td>4.</td>
<td>Avoid composite materials and make inseparable products from the same material</td>
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<td>5.</td>
<td>Avoid secondary finishes to materials</td>
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<td>6.</td>
<td>Provide standard and permanent identification of material types</td>
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<td>7.</td>
<td>Minimize the number of different types of components</td>
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<td>8.</td>
<td>Use mechanical rather than chemical connections</td>
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<td>9.</td>
<td>Use an open building system with interchangeable parts</td>
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<td>10.</td>
<td>Use modular design</td>
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<td>11.</td>
<td>Use assembly technologies compatible with standard building practice</td>
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<td>12.</td>
<td>Separate the structure from the cladding</td>
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<td>13.</td>
<td>Provide access to all building components</td>
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<td>14.</td>
<td>Design components sized to suit handling at all stages</td>
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<tr>
<td>15.</td>
<td>Provide for handling components during assembly and disassembly</td>
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<tr>
<td>16.</td>
<td>Provide adequate tolerance to allow for disassembly</td>
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<tr>
<td>17.</td>
<td>Minimize numbers of fasteners and connectors</td>
</tr>
<tr>
<td>18.</td>
<td>Minimize types of connectors</td>
</tr>
<tr>
<td>19.</td>
<td>Design joints and connectors to withstand repeated assembly and disassembly</td>
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<tr>
<td>20.</td>
<td>Allow for parallel disassembly</td>
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<tr>
<td>21.</td>
<td>Provide permanent identification for each component</td>
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<td>22.</td>
<td>Use a standard structural grid</td>
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<td>23.</td>
<td>Use prefabricated sub-assemblies</td>
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<tr>
<td>24.</td>
<td>Use lightweight materials and components</td>
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<tr>
<td>25.</td>
<td>Identify points of disassembly permanently</td>
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<tr>
<td>26.</td>
<td>Provide spare parts and storage for them</td>
</tr>
<tr>
<td>27.</td>
<td>Retain information on the building and its assembly process</td>
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</tbody>
</table>

Sustainable building and construction
Sustainable building and construction

bling buildings to recover materials. In particular, government can assist this shift by increasing waste disposal costs and providing tax advantages for recovered materials. The cost of land disposal of demolition waste is very cheap and is, in effect, subsidized by governments. Through significant increases in disposal costs, the rates of recycling and reuse of demolition waste also increase. For example, in Portland, when disposal costs were raised to over US$ 50 per metric tonne, the recycling rate of demolition waste jumped from about 20% to more than 50%.

Portland is also the location of a non-profit company, DeConstruction Services, which provides building owners with evidence of the value of materials recovered during their deconstruction activities. The materials are donated to another non-profit company that uses the materials to aid local charities in home construction; the owner, with this evidence in hand, can deduct a percentage of the value of the materials from income taxes. This provides a tremendous incentive for building owners to specify deconstruction rather than demolition for disposing of buildings.

The key non-economic instrument local governments can offer is to legislate that time must be provided for deconstruction when an organization applies for a demolition permit. Because time is the crucial factor needed for deconstruction, mandating that time be provided in the overall schedule for a new project involving demolition is of enormous assistance to businesses engaged in deconstruction and materials recovery.

Conclusions

Deconstruction offers an alternative to demolition that is not only an improved environmental choice but can create new businesses engaged in dismantling buildings, transporting recovered components and materials, remanufacturing or reprocessing components, and reselling used components and materials. Existing buildings, though not designed to be taken apart, are in fact being disassembled to recover materials. The benefits of increasing the recycling rates of materials from buildings from the 20% range to in excess of 70% are enormous, as waste from demolition and renovation activities can comprise up to 50% of national waste streams. Economic and non-economic policy instruments can assist in the shift from demolition to deconstruction by providing financial incentives and aiding in providing the time needed for deconstruction. In the developing world, building deconstruction practices offer a source of high-quality materials to assist in improving the quality of life and also the potential for new businesses that may provide economic opportunity for their citizens.

Notes