

Promoting the reuse and recycling of building demolition materials

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ABSTRACT: The demolition of constructed structures has earned a negative reputation for the construction industry due to the enormous amount of waste that is sent to landfills. Demolition waste reuse and recycling is, therefore, significant; it is a new and illustrative perspective on demolition waste management from the viewpoint of the building material lifecycle. It is discovered that demolition waste reuse and recycling plays important roles in value transformation for building material lifecycle, local economics, sustainable environment and nature resource conservation. In this research article, the authors aim to pinpoint demolition waste management in the lifecycle of building materials, and to examine various economic and environmental aspects of demolition waste reuse and recycling. In addition, the barriers, limitations and solutions for improving the implementation of demolition waste reuse and recycling are discussed in the article.

INTRODUCTION

The construction industry has been well accused for its enormous environmental impacts. In particular, construction and demolition waste generated from building and infrastructure-related activities form a major stream for municipal solid waste [1]. Among various construction activities that generate building waste, building demolition and renovation appear to be most the contributory [2][3]. Demolition waste has been imposing pressure on landfills in most communities and countries. To address these concerns, demolition waste salvaging for reuse and recycling (R&R) has been studied, attempted and practised in the construction industry for a long period of time [4].

On the other hand, the reuse of demolition waste concerns not only the demolition techniques adopted in a demolition project, but also a wide range of determinant factors, such as the local economic environment, secondary material market, regional construction and demolition activities, demolition project management approaches, natural resource availability, ecological systems and logistics. The combination of these factors sets demolition waste R&R as an important, yet complex, position in the building material lifecycle. In Particular, a piece of building material, after being extracted from the natural environment and going through manufacturing production, is inserted into a building to serve a period before it becomes waste following the demolition of the building.

The economic value of building materials, as well as environmental value, such as energy embodied, is tightly chained in the lifecycle of materials. Comparatively, building demolition waste R&R injects fresh contents into the material chain and lifecycle. In fact, the life of salvaged building materials extends through their reutilisation in a construction project or other applications. As a consequence, demolition waste R&R exerts a strong influence on environmental sustainability, local and regional economics, material markets, and, apparently, the attitude and approach of the construction industry.

In this research article, the authors aim to pinpoint demolition waste management in the lifecycle of building materials, and to discuss various managerial, economic and environmental issues within the waste building material supply chain. The purpose of this research is to promote environmentally and economically beneficial building demolition projects through material R&R.

DEMOLITION AND WASTE

Demolition is the last stage of building lifecycle after planning, design, construction and maintenance. After solely being concerned with the building construction phase, the industry has been shifting attention to the planning and design stages. Since the 1980s, maintenance has shared scrutiny due to some infrastructure crises caused by insufficient maintenance [5]. Recently, building demolition has been placed under the microscope due to increasing environmental pressures, in particular the issue of waste disposal. The reduction of building waste prior to, and after, they are generated onsite is considered crucial in achieving environmentally responsible building demolition projects.

Building Demolition

As building technology is evolving constantly, demolition keeps developing in equipment and techniques [6]. Currently, there are major demolition techniques that fall into three major categories, namely: mechanical demolition, deconstruction and implosion. Popular mechanical and implosive demolition techniques enable rapid and relatively simple demolition projects. However, these demolition projects yield enormous amount of building waste that is intermixed and contaminated, most of which end up as landfill [7]. To divert waste from landfill, building deconstruction, which was the only available demolition techniques in ancient times, has been revived recently as a mechanism to eliminate waste disposal and promote waste R&R [8]. In a deconstruction project, a building is carefully dismantled into its reusable components and materials. The processes of deconstruction are virtually the reverse of construction. Deconstruction is obviously a labour extensive and time consuming process, since large portions of the work needs to be undertaken manually. However, the environmental benefits of deconstruction are invaluable.

Demolition is technically advancing, thus its managerial approaches need to be adapted into new processes. In particular, waste building materials salvaged for R&R are enabled through innovative building demolition techniques; nevertheless, R&R is not explicitly achieved [9]. The availability of demand, the effectiveness and efficiency of information exchange, as well as the condition of the market significantly affect the outcomes of demolition waste R&R. Waste management plans play an important role in promoting waste R&R by thoroughly arranging waste production and the destinations of reutilisation. Currently, three major aspects are concerned within a waste management plan, namely: waste minimisation, waste R&R and waste disposal techniques [10]. In the case of building demolition waste management, waste R&R is the most important due to the difficulties and limitations encountered in minimising demolition waste, as well as a few options for disposal techniques, such as incineration. As a result, waste material markets that promote waste R&R are also crucial in order to eliminate the negative environmental impacts of building demolition projects.

Demolition Waste Management

From minerals that are excavated from the earth, most types of building material experience a series of adjunctive activities during constructional development before they end up in landfill. In addition to the visible process on the ground, landfill building materials are possibly transferred into mineral mines over a virtually infinite period, or the transformation is simply not reversible.

A building's lifecycle reflects an important component of the building material lifecycle. Building materials undergo various stages of a building's serving life, including procurement, construction, maintenance, refurbishment and demolition. At first, building materials are purchased and transferred from material suppliers. These materials are then combined into a building structure through construction activities. After undergoing certain periods of building service and maintenance, or renovation, the building might suffer aging structural problems or functional deficiency. When a decision on building demolition is made, building materials are generated from the structure and regarded as building waste. Finally, the building waste is most likely to be disposed of as landfill. On the other hand, demolition waste R&R add extra building lifecycles into a building's material lifecycle. In other words, the building material lifecycle is enlarged by repeating a chained building lifecycle. Moreover, the economic, environmental and social aspects of building material lifecycles are evolved and need to be explored and identified.

Demolition waste R&R is apparently beneficial to the environment. Firstly, as demolition waste is diverted from landfills through R&R, less waste materials are thrown directly into the environment. As a result, the environment is less polluted and more sustainable. Moreover, because building waste contributes a large portion of daily waste, reduced building waste streams decrease the need for landfills, which benefits land conservation. In fact, landfill shortage problems are current concerns of many metropolitan authorities [11]. Furthermore, while building waste R&R provides an internal supply for the construction industry, fewer raw materials are needed. Natural resource conservation is among the highest priorities of environmentalists. Conclusively, it is certainly worthwhile to investigate demolition waste management in the context of the building material lifecycle. Also, it is necessary to crystallise the social, economic and environmental implications of demolition waste management from the viewpoint of the material lifecycle.

EXPLORING R&R OF DEMOLITION MATERIALS

As faced in many countries, population growth and economic development offer enormous opportunities for the construction industry in terms of increasing demands for both residential and commercial buildings [7]. On the other hand, a huge number of aged buildings need to be demolished to claim land for new construction projects. In order to erect new building structures, the demolition of previous buildings that occupied the site is typically regarded as a preparation activity for the whole construction project. As scenario for each building demolition, including reason, location, budget and constraints, are varied one another, it is relatively difficult to regulate all demolition projects and their waste reuse using one ruler. In other words, waste reuse might be parameterised to the circumstances of the demolition projects. However, at a regional or national level, waste R&R tend to maintain a stable or steady figure in an ideal situation.

Demolition Material Flow

Generally, materials are physically transferred from one entity to another in the industry, although the party who possesses the materials and who process the materials are sometimes different and have complex and inter-crossed relationships. Building materials appear as having different status and forms, such as raw materials, building materials, building components, structures and whole building. Another method to observe building material flow is to identify material transfers among various construction activities.

After building planning, design and construction procurement, materials go through to construction sites from suppliers. These materials are then embedded into an entire building and serve in a building's life. During the building's lifespan, materials might also be transformed by activities like maintenance and refurbishment. At the end of a building's life, after a decision is made for building demolition, building relocation should be the first option taken into consideration, by which the entire building is relocated to another place and continues to function. In such a case, the building materials are reserved in the relocated building. While demolition must be performed, there should be a series of activities to salvage waste building material for R&R. For instance, after building materials are dismantled from a building, they go through a sorting process to separate different materials. Reprocessing is then likely needed to allow recovered building materials to be reutilised in construction projects. Or, in an ideal case, building materials from demolition projects can be reused directly without further processing. The concept of demolition waste R&R significantly affects a material's lifecycle. Materials that have served in a building's life are preferably reclaimed and repositioned for a new building's life or extend the life of an existing building. Practically, some durable building materials, such as metal window frames, can be repeatedly used in different building projects, rather than being disposed of after building demolition.

Microeconomic Influences of Demolition Material R&R

Building materials, identical to other commodities, have their associated economic value. During its own lifecycle, building materials alter in their economic value following the transformation that the materials go through. Moreover, the transformations of building materials are generally the consequences of human activities and sometimes natural routine movements. Human activities, according to their nature of economic influence on the building materials, can be classified as value adding, value declining and non-value related activities. Generally, a piece of building material goes through a pool of value related or non value related human activities till its retirement, from the chemical compounds in a mineral plant or other virgin nature resources to waste disposed at landfills. As a result, the financial value of the piece of building material, taking different forms, shapes or situations of existence, increases or shrinks regarding the human activities undertaken.

At one point, the economic value reaches its peak, which presents the most degree of usefulness of the piece of building material to the user or client. While as the least financial value of the building material occurs in the start and the end of its lifecycle. The economic value of a piece of building material is determined by the overall effects of value adding activities and value-consuming activities it experiences. This value is dynamic during the material lifecycle and various activities.

Three sequential stages are denoted in the building material lifecycle, namely the pre-construction, construction and post-construction periods. Most value adding activities are performed in the first two stages. Other activities in the third stage, such as renovation and maintenance, also promote the value of building materials. Through these activities, the value of a piece of building material accumulates to its highest level, while activities in the last stage of the building material lifecycle consume the value within the building materials and turn it back to zero. Activities like building use and demolition, normally over a relatively long period compared with activities in the first two stages of the building material lifecycle, are major components of the last life stage before disposal. The value of a piece of building material and its lifecycle is illustrated in Figure 1. As can be seen in the graph, activities cause the line to go up or down, indicating the increased or decreased value of the piece of building material.

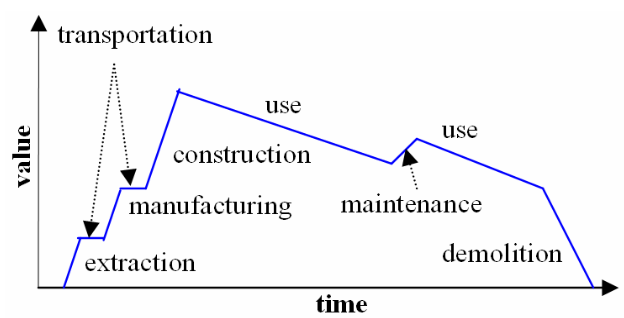

Figure 1: Lifecycle value chart of materials.

It should also been noted that non-value related activities, such as material marketing, transportation and inventory, also play a significant role in realising and facilitating value adding activities. However, because these activities do not directly create value for the building materials, they should be avoided or simplified in order to speed up the value adding process and minimise waste. For example, inventories are tightly controlled or eliminated in the manufacturing process, which is the central philosophy of Just-In-Time (JIT) [12]. Similarly, transportation is minimised and material marketing is facilitated and automated using logistic management and information technology [13]. Consequently, less human and monetary resources are spent on non-value adding activities during the building material lifecycle. However, the quality of these activities should be maintained so as to ensure the next human activity is able to carry on.

At the end of the building material lifecycle, building materials are dismantled and sent to landfills. This might indicate that the economic value of the building materials drops to zero. However, the end of a building's life does not necessarily lead to the end of the building materials' lifespans. Especially in the current situation of urban development, redevelopment and restructuring, large portions of erected building structures are demolished with spatial or functional, rather than structural or material, quality problems. For such a reason, at the point of demolition, a building, as an aggregation of building materials, is still functional. Therefore, either the whole building or the embodied building materials contain financial value that should not be neglected.

When the building materials that come out from a building demolition project are dumped into landfills, their value is also dumped and wasted. However, building material R&R helps to reserve the value within the building materials and extend their lifespans. Furthermore, the value of the building materials may reach another peak in another construction project and serve in another building structure. Indeed, the success of such transformations largely depends on many other factors, such as secondary material markets, local, national and international demands, information availability, R&R facilities and the amount of labour and costs involved.

Regarding the value curve of a piece of building material through its lifecycle, it is possible to improve its value by several means. That is, the ratio of performance and costs of the piece of building material can be enhanced, mainly in managerial aspects. For building materials, better performance denotes longer serving life and usefulness. It is possible to boost the value of building materials through the first two stages of the building material lifecycle. Ever-developing technologies facilitate the better quality of both building materials and building structure. As a result, at the same declining rate, building materials with better value and quality last longer. Secondly, the declining rate of the value of building materials can be slowed down through better maintenance and necessary refurbishments. These activities either reduce the speed of value shrinkage or promote the value to another higher level. Finally, and most importantly, when a building's lifespan has ended, building material R&R should be carried out. After being reprocessed and reused in other construction projects, the value of building materials, as they repeat through the first and second stages of the lifecycle, is promoted to the second peak value. If quality is maintained at a reasonable level, further reuse or recycling could also be possible. The value curve of those building materials is illustrated in Figure 2.

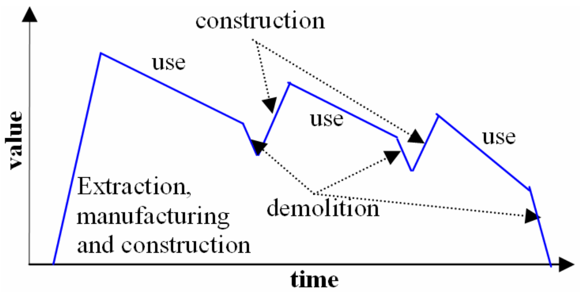

Figure 2: Lifecycle value chart of materials with R&R.

Macroeconomic Influences of Demolition Material R&R

From a micro view, the value of a piece of building material rises and falls during its lifespan. Demolition waste R&R promote value to another high point. On the other hand, from a broader viewpoint, building demolition waste, material lifecycles and R&R all play important roles in the economics at both the local and national levels, also inside and outside the construction industry.

Modern building technology is rapidly developing towards enabling building material salvaging after demolition. However, the present situation indicates that waste R&R is not guaranteed. Currently, waste R&R is often linked with public sectors and non-profit organisations. However, it is more motivated to have market-based actors within the theme. To achieve transactions, a secondary material market is necessary. It includes adequate technical knowledge, classification systems, reasonable profit margins, legislative support and, importantly, awareness from the construction industry and the community. Waste building material markets can take many forms. Among them, material exchange is a solution that has been put into practice in some industries for a long time. However, within the construction industry, material exchange has not been well developed. It has a slow growth rate, low availability and too specific a service range [14]. New technologies, including the Internet, insert new contents into waste material exchange by providing an ideal platform for information collection and retrieval. Nonetheless, low information availability and low actual transactions generated are problems associated with some current Web-based waste exchange systems [15]. It has also been suggested that the situation will improve if building demolition project management is more systematic and waste material oriented [16].

The waste building material market is improving, especially with regard to the economic value of dismantled building materials from demolition projects being gradually recognised, along with reinforced public awareness. While the market is sufficiently mature, waste R&R could be regarded as a widespread and common practice. Relevant management approaches and techniques also need to be advanced and adopted. It is a utopian situation that is financially beneficial to both waste building producers and consumers. Secondary or reprocessed building materials are then able to form a major, constant and steady stream for supplies of local construction activities, including infrastructure, housing and commercial buildings. As a result, the economic structure of regional industries is changing. The construction industry is now less dependent on the mining and manufacturing industries; instead, it largely depends on itself as an important source of input. To some extent, the construction industry becomes a self-sustaining industry.

Another macro aspect of waste building material R&R is the intensive labour involved. In contrast to mechanical or implosive building demolition, new demolition techniques that enable building waste for salvage, such as deconstruction, are generally labour intensive. Heavy human resources are necessary, not only for physical dismantling working onsite, but also for thorough planning and design to fulfil safety, economic and environmental constraints. As a result, demolition waste R&R provides rich employment opportunities in the local construction industry.

Environmental Impact and Energy Consumption

In the construction industry, the direction is set to minimise the waste sent to landfills and to conserve raw materials that are extracted for utilisation in construction projects. Traditionally, construction and demolition waste (CDW) is the concept to cover all the waste materials generated from construction related projects, including maintenance and demolition. Yet demolition waste is comparatively difficult to manage due to its huge quantity and non-singleness [3]. Therefore, demolition waste management plays a major role in improving the construction industry’s environmental performance.

Qualitatively, it is apparent that demolition waste R&R benefits the environment. In particular, from the point of view of building materials, the direct use of building materials that have served in buildings or building materials after reprocessing help to divert waste from landfills. Furthermore, waste reuse indicates that fewer raw materials from nature are required to manufacture building materials that are necessary for the construction industry. In addition, the manufacturing process of building materials is omitted, which leads to less energy consumption and pollution. Figure 3 illustrates the material circulation situation of the construction industry, comparing with situation involving demolition waste R&R. The latter seems more sustainable to the environment.

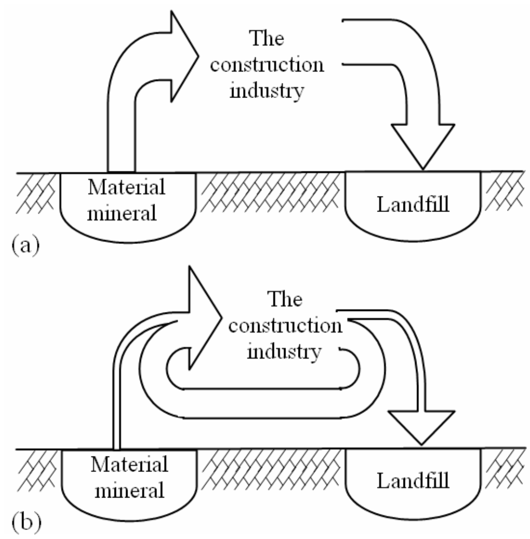

Figure 3: Sustainable construction by demolition waste R&R.

On the other hand, to actually show the benefits of demolition waste R&R, the environmental impacts of a building demolition project with or without material R&R need to be accurately quantified for the sake of comparison. Life Cycle Assessment (LCA) is currently a popular mechanism to evaluate the environmental impact of construction by figuring the total energy consumed during a product or a process [17]. In LCA, the environmental effects associated with extracting, processing, manufacturing, transporting, using and disposing of products are regarded as embodied. In the building industry, the object often under investigation is embodied energy. Although the energy required to operate a building structure is much more substantial than the energy consumed in the construction activities, other embodied resources, including those spent prior to construction, are in fact significant to the environment, including material extraction and manufacturing. LCA captures all the relevant environmental effects with a product or process over its full lifecycle.

A building structure comprises a variety of building materials. Therefore, a building's embodied energy comprises energy in its materials and others, including processes of construction and maintenance. Once a building structure is demolished for a particular reason, its life terminates. As a consequence, the energy embodied in the building materials vanishes. In other words, while building materials from building demolition end up in landfill without involving other buildings or products, the energy associated with them is virtually exhausted. The consumption of energy generally provides social and economic value to human beings by accommodating and transporting. However, the diminution and shortage of natural resources requires people to actively reserve their environment. Other signs also show worrisome situations, such as the greenhouse effect.

Given the pressure, there are numerous efforts paid within the construction industry to reduce the energy consumption of newly erected building structures. On the other hand, saving energy from construction projects does not necessarily mean that it will save the environment [18]. Most conventional methods to achieving energy efficiency use fuel-based products that inevitably damage the environment in many different ways.

In contrast, demolition waste R&R opens a new theme for energy conservation and environmental protection. As a final product, a demolished building terminates its lifecycle and its energy consumption is finalised. Although the energy used in its building materials can hardly be recovered directly from a dismantled building, the R&R of building waste materials remarkably affects the energy consumption of associated new construction projects. In particular, several processes are avoided in new construction projects that use demolition building materials, including the extraction of raw materials, manufacture of building materials and components, as well as relevant transportation [19].

Moreover, the additional processes of building materials manufacture are omitted, due to the use of raw materials instead of secondary ones. As a result, the energy and raw materials consumed in the avoided processes are recovered. That is, the energy consumed in a demolished building is finalised and cannot be saved, yet following construction projects that reuse and recycle building materials from demolitions incurs less energy consumption. In an ideal system, whereby building materials from demolition projects are maximally reused and recycled in other construction projects, the overall construction will have a much slower energy consumption rate, which will definitely benefit the environment.

IMPLEMENTING R&R OF DEMOLITION WASTE

Keeping the environmental pressure from government legislation and community concerns in mind, the construction industry has strongly sharpened its routine operations. Terms such as sustainability and environmental performance have become extremely popular within the industry. While practitioners are inevitably concerned with the profitability of construction projects, environmental concerns are gradually being increasingly recognised. Material R&R is being developed remarkably worldwide, and the situation can be regarded as promising. However, several long existing and newly generated obstacles deter the industry from moving towards a comprehensive atmosphere of building material R&R.

Marketing is apparently among the most crucial components in the lifecycle of a product [10]. Particularly in building materials from demolition projects, a robust market comprises supply, demand and transactions. The financial value of waste building materials is gradually being recognised; however, transactions of waste material between demolition project and demanders are not guaranteed. A secondary building material market, therefore, should be developed to provide financial incentives to material producers. Finding and satisfying demand is particularly important for demolition project owners who want to sell building materials. Currently, participation in secondary building material markets is generally low, although the market situation varies from country to country and region to region. It appears to have a relatively low economic share, difficult conducting of business and an unsatisfactory amount of transactions achieved [14][15]. The situation and strength of secondary building material markets might be diverse. However, there are several general problems that can be improved by the industry, community and government.

First of all, the authorities, local or national, should play a more supportive role in building waste building material markets. This includes providing legislative and financial incentives to waste related business. Legislation can be set up to disallow or discourage the disposal of reusable building materials [14]. Legislation also includes a higher tipping fee for the disposal of demolition waste into landfills. Moreover, while waste related businesses or workforces are often seen as hardly profitable and belonging to low-income communities, government subsidies can be used as a financial incentive to stimulate R&R businesses [20]. Financial support could cover various aspects, such as tipping fees, taxes and facilities.

Secondly, apart from governmental support as an external enforcement, the building industry itself needs to improve considerably in both technical and managerial aspects. Technically, the building industry always focuses on higher cost efficiency and lower environmental impact. In order to enable building demolition waste R&R, the processes of dismantling, sorting and processing building materials from a demolition project should be feasible and simplified. New building technologies, such as design for deconstruction, deconstruction and renewable materials, are still in their infant stages. While these technologies are more mature, building material reuse or recycling is automatically promoted.

In addition, a classification system and a qualification system should be built in order to support building material waste. Unlike manufactured products, building materials from a demolition project may be of uncertain types and quality. Classification and qualification systems help both waste producers and buyers to identify building materials, as well as evaluate usages. There can also be an associated coding to enable information technology applications. Apart from technical issues, managerial aspects need to be improved to support new technologies [9]. Demolition project management need to be differentiated from construction project due to the objective of waste R&R. For example, implementing Just-in-time philosophy into demolition project management speeds up the demolition process and promotes waste material R&R. Environmental performance evaluation methods, such as LCA, should be developed and extended in order to assess building demolition projects. Furthermore, information technology applications are needed to implement demolition project management in actual projects.

Finally, and most traditionally, community awareness has to be improved. There needs to be a genuine commitment to sustainability and environmental protection, rather than making it a marketing device [18]. Government campaigns and education are an effective means to improve the environmental awareness of the building industry and communities.

CONCLUSIONS

Demolition waste R&R is an efficient means to divert waste from landfills. Building demolition has evolved to enable and promote waste R&R. The changing situation has also led to the transformation of the building material lifecycle. From a holistic view, material flows in the construction industry are circulated through waste R&R after a building's demolition.

Conventionally, the economic value of a piece of building material reaches its peak after construction and drops to zero after demolition and disposal. Nonetheless, material R&R and reutilisation of recovered building materials in other construction projects enable the economic value of building materials to be boosted to another peak level after demolition. Demolition waste reuse also provides steady material supply for regional construction activities and stimulates employment opportunities for the construction industry.

Environmentally, building material reuse after demolition empowers the industry to sustain its material supply, as well as to lower natural resource consumption. Energy consumption by the industry is also moderated. However, obstacles exist that deter the industry from widespread adoption. It is recommended that a number of situations need to be improved in order to facilitate building waste material R&R, including government support, secondary building material market, industrial standardisation, building demolition techniques and management approaches, and increased community awareness of the industry.

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