American Journal of Environmental and Resource Economics
2021; 6(2): 46-53
http://www.sciencepublishinggroup.com/j/ajere
doi: 10.11648/j.ajere.20210602.13
ISSN: 2578-7861 (Print); ISSN: 2578-787X (Online)

Study on Recycling and Reuse of Waste Materials in Building Industry

Guangru Du[1, *], Ruinian Jiang[2]

[1]College of Urban and Rural Construction, Hebei Agricultural University, Baoding, China

[2]College of Engineering, New Mexico State University, Las Cruces, the United States

Email address:
gracedu2017@qq.com (Guangru Du), rjiang@nmsu.edu (Ruinian Jiang)

[*]Corresponding author

To cite this article:
Guangru Du, Ruinian Jiang. Study on Recycling and Reuse of Waste Materials in Building Industry. *American Journal of Environmental and Resource Economics*. Vol. 6, No. 2, 2021, pp. 46-53. doi: 10.11648/j.ajere.20210602.13

Received: May 1, 2021; **Accepted**: May 24, 2021; **Published**: June 7, 2021

Abstract: Treatment of rapid growing large quantity of waste materials has been recognized as a major issue in the modern construction industry. It has great impact on both the efficiency and environment of construction projects. Recycling reduces original-resource production so that the environmental impact can be reduced. Simultaneously, recycling brings benefits to the economy. The United States has done a lot in recycling and reuse in building industry, but there are still some insufficient in this area. While China keeps more and more attention in recycling and will try hard to improve the proportion and widen the measures of recycling. From the perspective of these two counties, this paper describes the current state of recycling and reuse of waste materials in the building industry, analyzes the benefits, and puts forward the measures for reuse of waste materials. The paper indicates that the recycling and reuse of waste materials has multiple benefits. Waste materials can be used directly or reused through simple or complex processing, and they can be reused for the same purpose or for a different purpose from the original one. More efforts should be made in recycling and reuse of the construction waste materials.

Keywords: Sustainable Building, Waste Materials, Recycling, Reuse

1. Introduction

Buildings occupy a considerable space and require a large quantity of materials for the construction. The restoration and demolition of buildings generate large volume of different types of wastes. For example, the quantity of wastes produced by the Building Industry accounts for about 1/3 of the total quantity of wastes in China [14]. Today the treatment of waste becomes more and more important with the short supply of resources and the higher requirement of environment protection. Professionals of the industry are required to manage the wastes in more efficient ways, including recycling building wastes, improving materials' durability, and limiting the use of materials that may pollute the environment [9].

Unfortunately, many countries, including developed countries, still throw a lot of building wastes away without any treatment. In the USA, while recycling more than 60 million tons of municipal solid waste annually, more than 130 million tons of solid wastes are simply landfill treatment every year [12]. The building demolition and construction waste makes up over 40% [16] of the total waste into landfills in many areas of America.

Every building has its purposes and need use a certain quantity of materials, therefore, it is difficult to decrease volume by simply downsizing the scale of buildings. From this point of view, recycling and reuse of materials and components of buildings could become a solution for the reduction in the final volume of waste. It is also necessary to encourage recycling in the Building Industry for a sustainable development of the industry. With the declining of the materials availability, it forces the market to change demand to other goods. One way is to foster an effective recycling system. In this paper, the benefits of recycling and reuse of waste materials are analyzed, and the source of building waste materials, and the methods of reusing and recycling of building materials are explored. Strategies for recycling and reuse of waste materials in the building industry are proposed.

2. Benefits of Recycling and Reuse of Waste Materials

The benefits of recycling and reuse of building waste materials are compared with other waste management practice including landfill and incineration. The benefits are summarized into six categories that are described in the following sections.

2.1. Avoiding Natural Resource Depletion

Natural resources cannot be reproduced and will be used up if the present assumption rate continues. Recycling materials can reduce using primary raw materials and leave them for future use.

2.2. Reducing Energy Consumption and Carbon Emissions

Materials, especially some metals, can be recovered from manufacturing wastes or end-of-life products, which decrease energy consumption and the attendant environmental impact. The recovered materials can serve as secondary resources and substitute for the primate raw materials.

2.3. Economic Benefit

Recycling can sometimes bring benefits by saving money. In China, fixed assets have been continuously increased in recycling and reuse of waste materials of construction. The total newly increased fixed assets on recycling and disposal of waste is 667.94 billion Chinese yuan (about 102.20 billion US dollars) in 2013, 923.29 billion yuan (about $139.89 billion) in 2014, and 1072.08 billion yuan (about $162.44 billion) in 2015 [17]. Unfortunately, the fund is not sufficient for establishing an effective recycling system for many products. The Chinese government is developing policies to help build recycling systems and increase recycling rates.

2.4. Market Stabilization

Materials market is subject to all the vagaries that confront any business. Shortage of materials may cause price variation or even slowdown of the progress of the production [13]. It is costly with adding or removing capacity to keep materials market stable. Secondary production from waste recycling allows materials markets to be more resilient regarding to natural fluctuation in demand by bringing more flexible expanding and contracting capacity [2].

2.5. Reserved Historical Values

Waste materials removed from old buildings may have their unique features. Reusing these materials in proper places will add historic features to the new buildings, especially in antique construction or museum.

2.6. Creation of New Employment Opportunities

When waste materials are recycled, new manufacture industries are created that will create new jobs. The contributes in wages, tax and jobs by waste material recycling are summarized in Table 1 and illustrated in Figures 1 and 2 [22]. It is clearly shown that recycling helps to create new well-paying jobs, and contributes to wages and tax to the country. The contribution by C&D (Construction and Demolition) is the largest. As a result, recycling and reuse of waste materials from building industry brings a lot of benefits to the society.

Table 1. *Estimates of contributions of recycling to U.S. economic activity/quantity and value contribution.*

Metric	Total	Percentage of US Economy (2007)
Jobs	757,325	0.52%
Wages	$36,636,597,000	0.62%
Tax Revenue	$6,795,244,000	0.9%

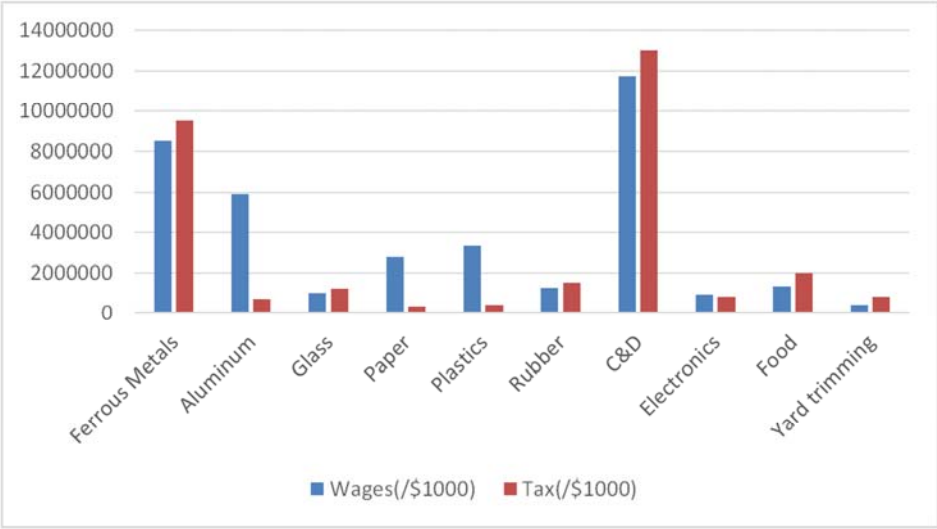

Figure 1. *Wages and tax attributable to recycling in 2007, USA (in $1000).*

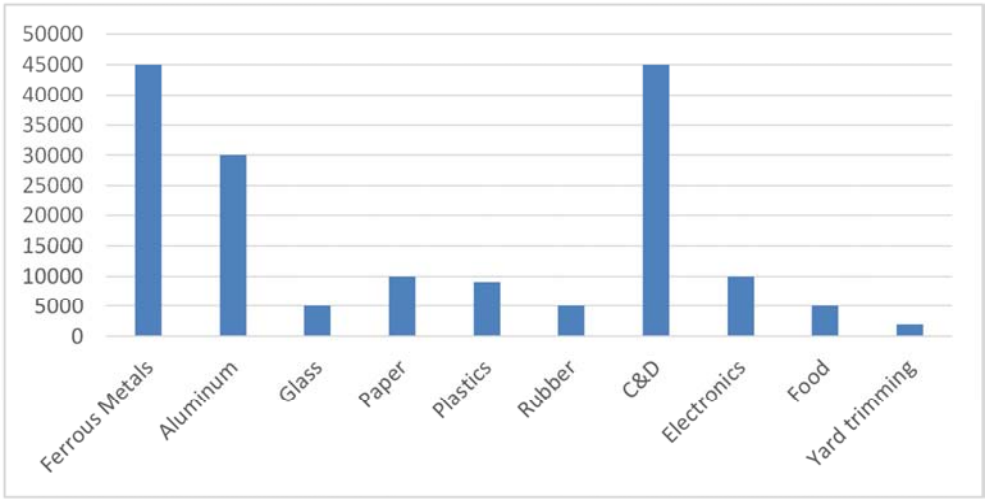

Figure 2. *Jobs (number) attributable to recycling in 2007, USA.*

3. The Source of Building Waste Materials

Building waste materials include abandoned materials produced during the process of construction, reconstruction or expanding, maintenance, and demolition of all kinds of buildings [6]. The building waste materials may come from deconstruction of old buildings, or construction of new buildings.

3.1. Constitute of Building Waste Materials

Construction and demolition (C&D) wastes are residues from construction, reconstruction, extension, alteration, maintenance and demolition of buildings and other infrastructures. These wastes consist of various types of materials, and a heterogeneous residue can contain any material that is part of a building or infrastructure as well as any other materials used during construction work [24]. C&D wastes can be composed of [7]:

a. Concrete, bricks, tiles and ceramics; Vieira, CS and Pereira, PM
b. Wood, glass and plastic;
c. Bituminous mixtures, coal tar and tarred products;
d. Metals;
e. Soil (including soil excavated from contaminated sites), stones and dredging spoil;
f. Insulation materials and asbestos-containing construction materials;
g. Gypsum-based construction materials; and
h. Other construction and demolition materials.

The C&D waste composition by material (before recycling) is shown in Figure 3 [21, 22] for 2013 and 2014 in the US. It is observed that concrete is the largest amount produced, accounting for 65%-70%. The second composite is asphalt concrete, which accounts for 15%-20%, and all the other parts account for less than 20%. The composition of waste materials did not change much between 2013 and 2014.

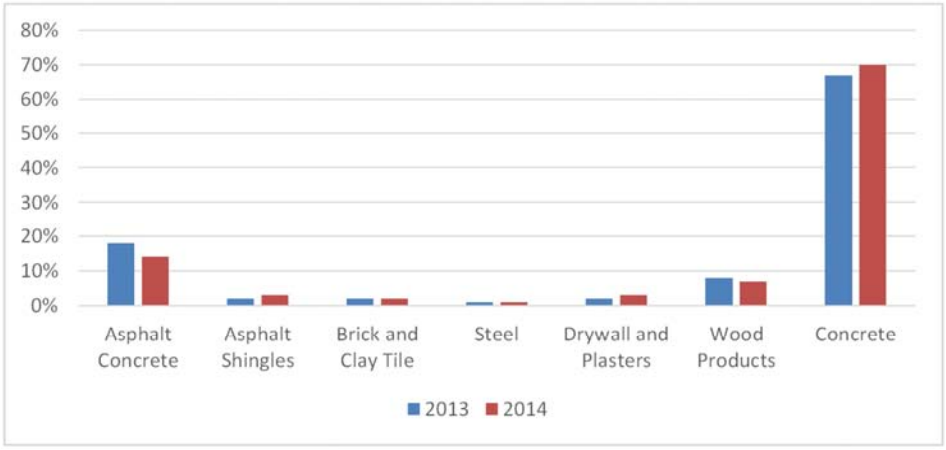

Figure 3. *C&D waste composition by material (before recycling).*

Figures 4 and 5 [21, 22] show the C&D debris generation by material and activity in 2013 and 2014 in the US, respectively. The total concrete generated was 350 million tons in 2013, and 375 million tons in 2014. The total asphalt concrete generated in 2014 was smaller than that in 2013. In these two years, the waste generated during the construction

was much less than those generated in the demolition.

Figure 4. *C &D debris generation by material and activity (million tons) in 2013.*

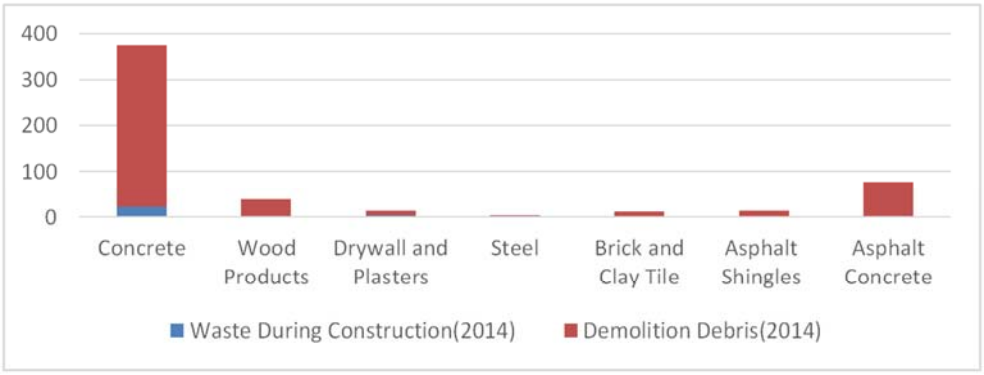

Figure 5. *C&D debris generation by material and activity (million tons) in 2014.*

The basic five categories of construction materials can be roughly divided into polymer materials, metal, wood, inorganic masonry, and cement and ceramic. The proportion of the five categories of construction waste is different. The proportions of waste are compared in Table 2 [19] between construction of new buildings and demolition of old buildings in China. Concrete also accounts for the most part of waste materials, and more is generated from demolition than from construction. It is interesting that some wastes, like dregs, stone & gravel, bamboo & wood, is generated less from demolition than from construction.

Table 2. *The constitute of building waste materials [19].*

Ingredient	Proportion (%)	
	Demolition of old building	Construction of new building
Pitch	1.61	0.13
Concrete	54.21	18.42
Dregs	11.91	30.56
Stone & gravel	11.78	23.87
Bamboo & wood	7.46	10.83
brick	6.33	5
glass	0.2	0.56
plastic	0.61	1.13
sand	1.44	1.7
medals	3.41	4.36
others	2.25	4.22

3.2. Current Situation in Recycling Waste Building Materials

Large number of skyscrapers has been built in many countries since 2000 as a result that people in big or medium-sized cities blindly respected landmark buildings. It produces a plenty of urban wastes, and how to deal with these wastes has become a challenging environment issue. For example, the amount of construction waste in China has accounted for 30% to 40% of the total municipal waste. About 500 to 600 tons of waste are generated from every ten

thousand square meters of buildings, and 7,000 to 12,000 tons are generated from demolition of 10,000 square meters of old buildings [5].

In 2010, residents of the Organization for Economic Co-operation and Development (OECD) countries collectively generated well over 600 million tons of municipal solid waste (MSW). In general, developed countries generate more wastes than the developing countries. For example, countries such as Norway and the USA discard more than 2kg per person per day, while Mexico, Poland and others discard less than 1kg per person per day [18]. The recovery of waste also varies among countries. For example, in Switzerland in 2009, 51% of medal solid waste was recovered for recycling or composting [8]. In USA in 2008, a little over 33% of medal solid waste was recycled or composted [20].

The U.S. Environmental Protection Agency (EPA) has been collecting and reporting data on the generation and disposition of waste in the United States for more than 30 years. As shown in Figure 6 [22], about 258 million tons of municipal solid wastes (MSW) were generated in 2014 in the United States, out of which over 89 million tons of MSW were recycled and composted, equivalent to a 34.6 percent recycling rate. It can also be seen that the total of generation of MSW grew quickly from 1960 to 2005, but slowed down from 2005 to 2014. The rate of recycling of MSW grew slowly before 1985, and speeded up after 1985. The efforts on reducing wastes are helpful in slowing down the generation of MSW, while recycling rate can be increased by more public attention and a better efficiency of the ecological implementation.

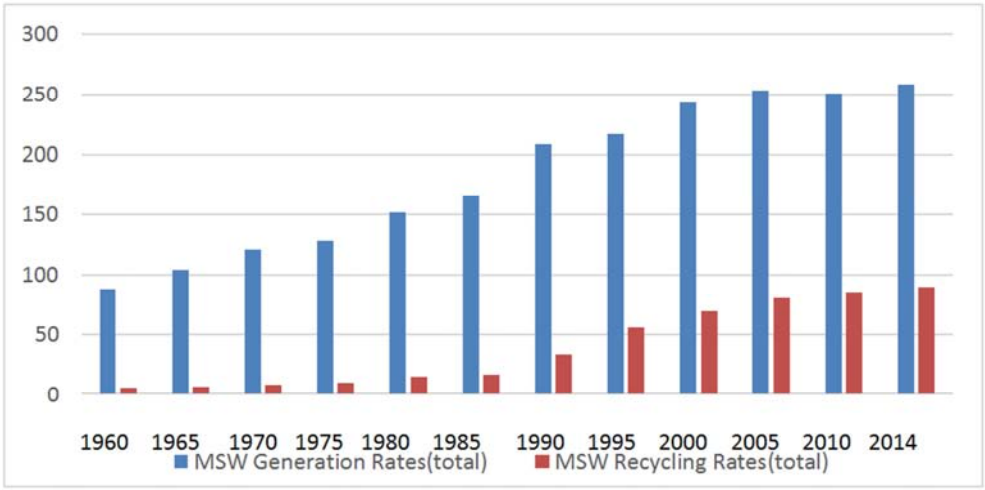

Figure 6. *Contrast of MSW generation rates and recycling rates (total: million tons).*

4. Measures of Reuse and Recycling of Building Materials

4.1. Direct Use of Waste Materials

Waste materials in a good condition can be directly recovered or through simple treatment, then be reused to new buildings. These reused materials can achieve bigger economic benefits, and reduce the building trash.

4.1.1. Reuse of Old Materials from Demolition

Waste materials like bricks and tiles can be directly used if they are in a complete condition. Old materials from demolition can be used in different ways. It is optimal if the old materials can be used in historic buildings because they can be consistent in color and style with the original one.

Waste materials can also be used in new buildings. As the old materials may give people historical feelings, they can add traditional and vintage building characters to the new buildings.

4.1.2. Reuse of Old Building Components

The components from old buildings including doors, windows, wooden and steel frame elements can be conveniently disassembled and reused. These components, especially for some of the standardized wooden and steel components, can be used with little treatment.

4.2. Use of Waste Materials Through Processing

A lot of waste materials may not be used directly, but can be used after processing. Sometimes unexpected effects can be achieved through processing and reuse.

4.2.1. Recycling of Waste Wood

Wood has its unique feature, such as easy making, simple processing, convenient transportation, and repeatedly disassembling or using. Wood is widely used in buildings and landscape constructions.

Wood dismantled from old buildings can be cut into various shapes and sizes for reuse. In addition, the waste can be recycled into wood chips for composite products, incinerated for energy generation, or ground up and used as compost [11]. Wood furniture can be used directly or as new functions through a simple change. For example, an old window can be used as a surface of a table, and a waste door can be changed to a bookrack.

Figure 7 summaries the applications of recycled wood from 2016 Recycling Economic Information (REI) Report of US

[23]. It is shown that wood, including engineered wood products, wood flooring, and others can be recycled. Unfortunately, only 1% of wood have been reused or recycled, and it may be reused as the original or in other places.

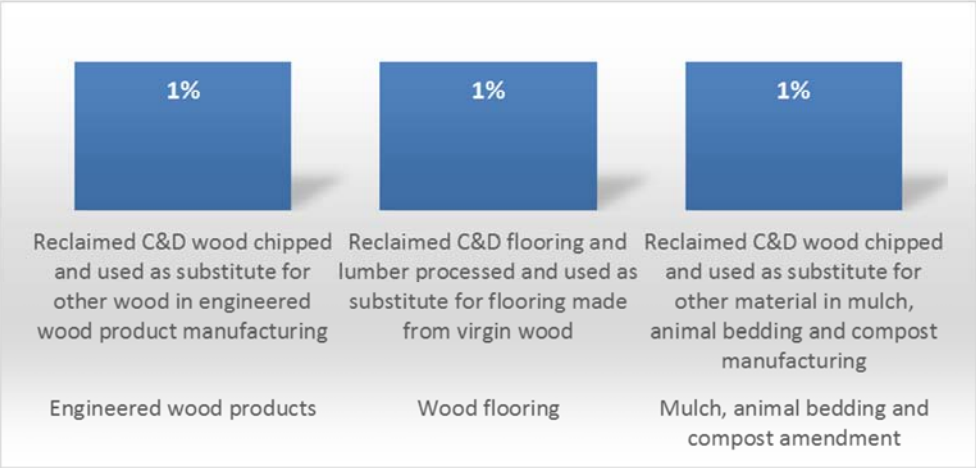

Figure 7. *Applications of recycled wood proportion.*

4.2.2. Recycling of Waste Concrete

Concrete is composed of gravel, sand, cement and water. It is widely used in civil engineering for its flexibility, low price, radiation protection, thermal insulation and waterproof, as well as simple manufacturing process. There are number of adverse effects during the manufacturing process of concrete. Mining can cause deforestation, topsoil loss, and erosion. Also, water runoff from mining can spill into freshwater and harm local flora and fauna [15]. Furthermore, dust emissions, carbon dioxide, sulfur dioxide, and partially combusted organic materials can reduce air quality [1]. During the final life stage of concrete, waste generated from its demolition may be minimized if the concrete can be crushed and down sized as aggregate into new batches of concrete. It can be 100 percent reused as aggregate in roadbeds or as a granular material [4]. With the continuous improvement of science and technology, waste concrete can be used in a wider scope. It can meet the requirements of different designs and can be used in low grade constructions.

The use of recycled concrete is shown in Figure 8 from 2016 Recycling Economic Information (REI) Report Methodology of USA. Two main use of recycled concrete are aggregate for road base and the construction fill, each account for about 10.2% [22]. Other use of waste concrete is very limited.

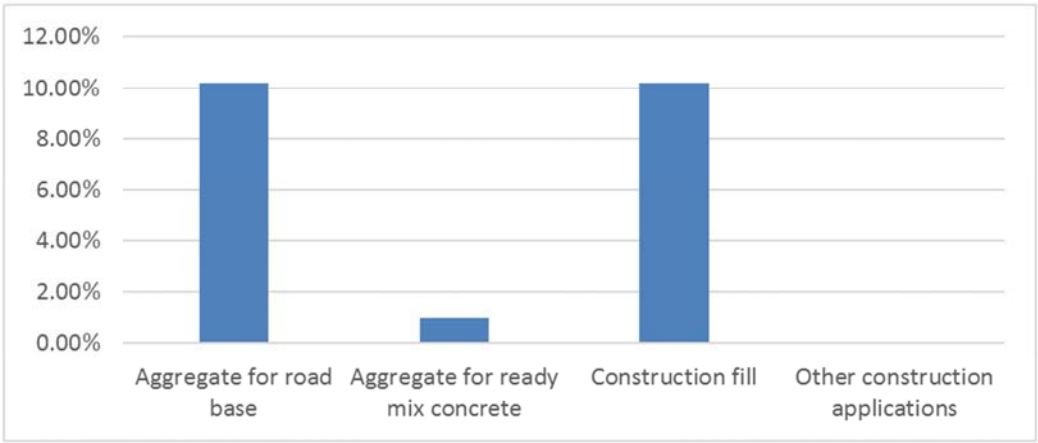

Figure 8. *Application proportion of recycled concrete.*

4.2.3. Recycling of Waste Masonry

Compared to other materials, the masonry which is larger and heavier, can be used after a simpler processing. Brick and stone are two main kinds of masonry.

As a traditional material, bricks are either hollow or solid. Bricks referred here are made from clay, not concrete masonry unit. The clay bricks demolished from old buildings can be directly used in other buildings with different arrangement by regular or irregular rotation, forward or backward changing. Old bricks, especially gray ones, can be used in repairing historic or antique buildings, which will present elegant and solemn appearance for their delicate texture and natural color.

Stone, including natural and artificial stone, is a common material for old buildings. It plays an important role not only in the building bearing but also in the building decoration. It is widely used in the outdoor and indoor environment for its

unique color and texture. Stone removed from old buildings, for its hardness and solidness, can be used directly, and can also be used as a new one after being polished.

4.2.4. Reuse of Metals

Most of metal materials are present in the state of the compound, and metals have their own physical properties including gloss, ductility, and conductivity. According to their characteristics, metal materials are usually used for load-bearing and decoration. Aluminum and steel are two of primary metals in construction.

Aluminum is highly workable, lightweight, durable, and strong metal that requires little maintenance. There are three drawbacks of aluminum: strip mining causes the loss of trees and soil, processing and manufacturing generates large quantities of waste, and needs large amount of energy [3]. To decrease the ecological influence during manufacturing, recycled aluminum can be used rather than bauxite ore. Construction with aluminum is very advantageous for its light weight and strength. And it requires little maintenance for durability. Though it is very sustainable during the use, it is not durable during demolition, especially for the mixed-material assemblies. In order to recycle and reuse waste materials efficiently, mixed one should be avoided during construction.

Steel is an alloy made of iron and carbon. It is strong, durable, and workable. Steel is a universal load-bearing material in buildings. Steel often corrodes and need more maintenance and more frequent replacement than aluminum. There are two defects of using steel: damage to land or wildlife, and pollution to air. Steel is one of the most recyclable construction materials available, because it can be easily separated from the waste stream magnetically and then processed into a high-quality alloy [10].

Metal materials may have prominent color, when they are used as decoration, they may appear different and beautiful characteristics. With people's aesthetic improvement, more and more metal materials are used to decorate, and the most convenient way to metal materials can be processed into art ornaments. The medal removed from old buildings sometimes will be made into a chair, a door or a unique statue.

4.3. Use of Waste Materials for Other Purposes

Old materials can be used by changing their original purposes. For example, a piece of old steel plate can be reused for a nameplate. As shown in Figure 9a, the name tag plate and the sculpture at the west gate of Chengdu Music Park in China is made of waste medal. Beer bottles can be used for decoration. For example, Figure 9b shows a house in Huston in the US whose walls are made of beer bottles. Old concrete can be smashed and poured to make flowerpots, as shown in Figure 9c.

(a) West gate of Chengdu, China (b) Beer house in Huston, USA (c) Flowerpots

Figure 9. *Example of waste materials for other purposes.*

5. Conclusions

Building industry usually generates large quantity of wastes, therefore, recycling and reuse of building wastes can promote a sustainable development in building industry. Recycling and reuse of waste materials can also bring other benefits including economic return, stable market, and generation of new jobs. People have started to recycle and reuse building wastes, but the rate of recycling is still very low. Building wastes can add various values if being used in a proper place and an appropriate way. If the building waste is in a good condition, it can be used directly; if it is damaged, it can be used after processing or in a lower level structure or decorations.

It is necessary to continue to explore the way of recycling and reusing building wastes. It is difficult to achieve a full use of all the waste materials, but potentials exist. Priority should always be given to recycling and reuse of waste materials, and broader approaches can be used with an open mind. On one hand people should try to reuse the materials obtained from demolished buildings, and on the other hand the building industry should design new buildings with a goal that the building elements could be easily reclaimed in the future. The government agencies should provide more financial support and establish policies to encourage ecological building projects. At the same time, the selection of designers and contractors should be based on their willingness to green building options, and innovative approaches for a more sustainable development.

Acknowledgements

This research is supported by Hebei Provincial Department of Human Resources and Social Security for oversea students. The project number is C201813.

References

[1] Allen, E and Lano, J., 2004. Fundamentals of Building Construction: Materials and Methods Hoboken, NJ: John Wiley & Sons, 468-499.

[2] Alonso, E., Field, F. R., Kirchain, R. E., 2008. A Case Study of the Availability of Platinum group Metals for Electronics Manufactures. IEEE International Symposium on Electronics and the Environment, San Francisco, CA.

[3] Bauer, D and Siddhaye, S., 2006. EBM Roadmap Summary. [online]<http://www.wtec.org/loyola/ebm/usws/ind> summary.htm, accessed in October 2017.

[4] CAC, 2010. Cement Manufacturing. [online]. <Http://www.cement.ca/>, accessed in October 2017.

[5] Cao Xiaolin and Liu Renhai., 2009. Study on the Resource Regenerative Utilization and Multistage Utilizaton of the Consturction Garbage. Constucton Economy. 2009 (6), 91-93.

[6] Chen, Jialong., 2010. Construction waste recycling use and regeneration process. Beijing Institute of Civil Engineering and Construction. (9), 44-49.

[7] ECD, 2000. European Waste Catalogue European Commission Decision. 2000/532/EC).

[8] EEA, 2010. The European Environment: State and Outlook 2010. European Environment Agency. Luxembourg, Office for Official Publications of the European communities.

[9] Ferek, B et al., 2016. Recycling and reuse of chosen kinds of waste materials in a building industry. IOP Science. 145, 1-9.

[10] Fernandez, J., 2006. Material Architecture: Emergent Materials for Innovative Building and Ecological Considerations. Burlington: Architectural Press, 109-152.

[11] Friedman, A., 2012. Fundamentals of Sustainable Dwellings. Washington: Island Press, 88-93.

[12] Kirchain, R. and Alonso, E., 2012. Materials availability and recycling: Fundamentals of Materials for Energy and Environmental Sustainability. Ginley, S. D and Cahen, D., 549-564.

[13] Lee, H. L., Padmanabhan, V., Whang, S. 1997. The bullwhip effect in supply chains, Sloan Management Rev. 38 (3), 93-102.

[14] Li, Dahua and Sheng, Zhoufa., 2006. Current situation of construction waste in our country and its reclamation management discussion. Journal of Anstiture of Architecture & Industry. 14 (6), 67-70.

[15] Mehta, K. P., 2001. Reducing the Environmental Impact of Concrete: Concrete Can be Durable and Environmentally Friendly. Concrete International, 61-66.

[16] Montoya, M., 2011. Green Building Fundamentals, 94-98.

[17] NBSC, 2014-2016. China Statistical Year Book. National Bureau of Statistics of China.

[18] OECD, 2010. Municipal Waste in OECD Fact book 2010. Economic, Environmental and Social Statistics, Paris, OECD Publishing.

[19] Qin, Zhongfu., 2013. Comprehensive Utilization and Countermeasure of Construction Waste. Institute of Civil Engineering and Management, School of Civil Engineering and Architecture, Zhejiang University.

[20] USEPA, 2009. Municipal Solid Waste Generation, Recycling, and Disposal in the United States. Facts and Figures for 2008, Washington, DC, US Environmental Protection Agency, P. 12.

[21] USEPA, 2015. Advancing Sustainable Materials Management. United States Environmental Protection Agency: 2013 Fact Sheet, June 2015.

[22] USEPA, 2016a. Advancing Sustainable Materials Management. United States Environmental Protection Agency: 2014 Fact Sheet, Nov 2016.

[23] USEPA, 2016b. Advancing Sustainable Materials Management. United States Environmental Protection Agency: 2016 Recycling Economic Information (REI) Report Methodology, Oct. 2016: 95.

[24] Vieira, C. S. and Pereira, P. M., 2015. Use of recycled construction and demolition materials in geotechnical applications. A review Resources, Conservation and Recycling (103), 192-204.