Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 118 (2015) 1296 – 1304

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on Sustainable Design, Engineering and Construction

Design for Disassembly and Deconstruction - Challenges and Opportunities

Fernanda Cruz Rios[a,*], Wai K. Chong[a], David Grau[a]

[a]*Arizona State University, University Drive & Mill Avenue, Tempe, AZ 85281, United States*

Abstract

Construction waste management has become extremely important due to stricter disposal and landfill regulations, and a lesser number of available landfills. There are extensive works done on waste treatment and management of the construction industry. Concepts like deconstruction, recyclability, and Design for Disassembly (DfD) are examples of better construction waste management methods. Although some authors and organizations have published rich guides addressing the DfD's principles, there are only a few buildings already developed in this area. This study aims to find the challenges in the current practice of deconstruction activities and the gaps between its theory and implementation. Furthermore, it aims to provide insights about how DfD can create opportunities to turn these concepts into strategies that can be largely adopted by the construction industry stakeholders in the near future.

Peer-review under responsibility of organizing committee of the International Conference on Sustainable Design, Engineering and Construction 2015

Keywords: Deconstruction; Design for Disassembly; Sustainable Design; Recyclability; Sustainable Construction; Recycle; Reuse; Sustainability.

---

1. Introduction

The improvement of sustainability in construction means the improvement of construction industry as a whole. A sustainable project has to be delivered by an integrated, planned and well managed construction process [1]. Deconstruction is the process of dismantling a building in order to salvage its materials for recycle or reuse.

---

* Corresponding author. Tel.: 1-520-328-7755
E-mail address: fcrios@asu.edu

Peer-review under responsibility of organizing committee of the International Conference on Sustainable Design, Engineering and Construction 2015
doi:10.1016/j.proeng.2015.08.485

The deconstruction process requires changes to the progress of construction methods, process and planning.

Although studies and case students were conducted, and guidelines were developed to address deconstruction, there are still challenges acting as barriers to its implementation [2].

Also known as "construction in reverse", deconstruction is a newer terminology for an old practice. Native American, through their migratory patterns, built their shelters in such a way to ease future disassembly. The Mongolian's yurt is a well-known structure that is designed for disassembly and deconstruction. Augenbroe and Pearce (1998) mentioned deconstruction as an expected challenge on near future, mostly due to need of adaptation of design processes and materials' market. Other researchers have also assessed and documented the benefits and opportunities for the developing of similar deconstruction practices [2,3,4,5,8,11,13,14,16,17,18,20,21,22,24]. Nonetheless, waste management is still a large concern in the construction industry. In the U.S., 160 million tons of Construction and Demolition (C&D) waste is generated annually. This amount represents a third of total solid waste stream [3]. In the year of 2000, demolition was responsible for 90% of all C&D waste [4]. Previous studies agreed that the Design professionals have the most important role to revert this situation [2,3,5,6,7,8,9,10]. The objective of facilitating deconstruction activities and materials' salvage, and the development of the concept of DfD are extremely important as they would close the construction materials' loop [2].

2. Objective and Scope

The main objectives of this research are to: 1) assess the social, economic and environmental impacts of deconstruction as a feasible alternative to demolition, and 2) assess the influence of DfD into the deconstruction process as one integrated and efficient strategy to close the construction materials' loop. This paper presents the first step of a series of research – an analysis on the challenges of deconstruction and of DfD opportunities. The analysis will assess the foundation for the development of the concepts of deconstruction and DfD, and to develop the opportunities for the assessment and measurement of the deconstruction and DfD processes.

3. Design for Disassembly

DfD is practice to ease the deconstruction processes and procedures through planning and design. Deconstruction is the process of demolishing a building but restore the use of the demolished materials. The deconstruction process essentially changes the traditional waste management process. The DfD process is an important strategy to conserve raw materials [11]. Figure 1 illustrates how DfD functions as a Reduce, Reuse and Recycle (3R) processes. The 3R processes eliminate the need for composting, burning and disposing of waste. Each process and the associated sub processes are shown in Figure 1.

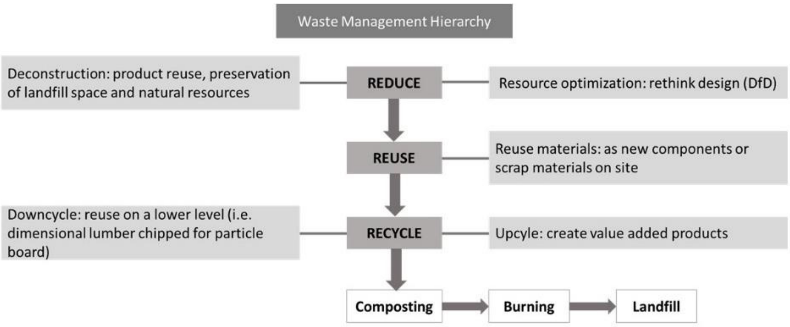

Fig.1. Waste Management Hierarchy. Adapted [5].

The key principles of DfD include: 1) proper documentation of materials and methods for deconstruction; 2) design the accessible connections and jointing methods to ease dismantling (e.g. minimizing chemical and welding connections and using bolted, screwed and nailed connections, using prefabricated and/or modular structure); 3) separate non-recyclable, non-reusable and non-disposal items, such as mechanical, electrical and plumbing (MEP) systems; 4) design simple structure and forms that allow the standardization of components and dimensions; and 5) design that reflects labor practices, productivity and safety [13].

Despite the hype of the concepts of deconstruction and Design for Disassembly among the practitioners, it has yet achieved success in the industry due to its impracticality imposed by codes, standards and professional practices. [2]. For example, building professionals will find it extremely challenging to integrate the concepts into their designs as they do not have the freedom and control over project schedule and cost, and they also face non-availability of materials. In order to successfully implement these concepts, there is a need to change the practices, perceptions and methods of delivery of different stakeholders. The market has to agree to develop and market these products, and the reuse/recycling market has to be matured enough to accept and sell these materials. [4,12]. That Norway has been able to generate zero waste and import more wastes to run their power plants clearly indicates the feasibility of the concepts.

Several other variables can interfere with the decision making process on the use of the concepts of deconstruction and DfD. These variables can be related to project objectives (e.g., time, cost, expected results, quality, and safety) or to project conditions (e.g., project scope, market, hazardous materials, site accessibility, and resources). The U.S. Department of Defense published a decision making matrix to help to identify these variables [14].

4. Benefits of deconstruction

4.1. Environmental benefits

Deconstruction and DfD are essential concepts to closing the loops of materials. A closed loop, similar to the cradle to cradle model, is an analogy to the biological metabolism present in Nature, where “waste” is turned into “feed” [15]. Also known as technical metabolism [9,15,16], this endless cycle turns the reused and recycled waste into “nutrients” (i.e. new materials or uses) for new buildings. Figure 2 shows how the materials flow into a cycle when reusing and recycling activities are implemented.

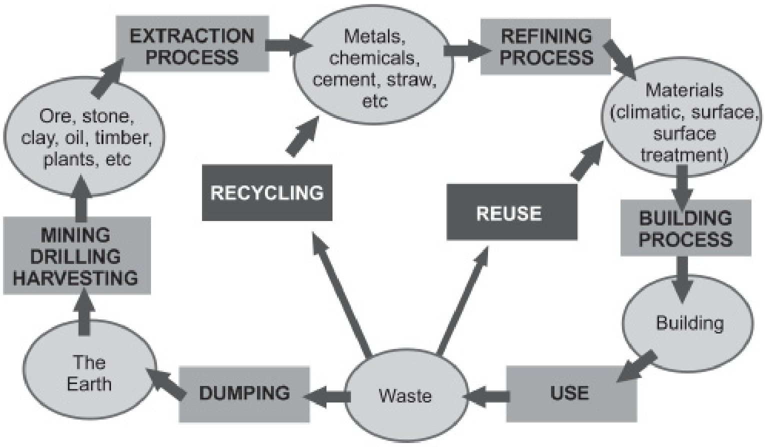

Fig. 2. Closing the loop in the material lifecycle. Adapted [2].

The environmental benefits of closing the loop include 1) extending the life of raw materials mines; 2) lower the cost of materials (if the supply chain is mature); and 3) reducing the embodied energy and carbon emissions of the construction industry [2,16].

(Subsection Heading)

A measurable way to better understand the contribution of deconstruction into the materials lifecycle is the waste diversion rates. The waste diversion is by far one of the most impactful consequences of deconstruction [2,3,4,5,14,17,24]. Table 1 shows the reuse/recycling rates of different cities in the USA (taken from various literatures). Deconstruction reduces the disturbance of a site and contributes to a reduction of landfill areas.

Successively, DfD helps to produce more flexible and adaptable buildings, with components that are more easily maintained and repaired. The overall environmental impact would be reduced as a result.

Table 1. Recovery rate for various deconstruction projects. Adapted [4].

Location	Case Study	Reuse/Recycling Rate
San Francisco, CA	Presidio	87%
Fort McCoy, WI	USArmy Barracks	85%
San Diego, CA	US Navy Motor Pool Building	84%
Marina, Ca	Fort Ord	80-90%
Twin Cities, MN	Army Ammunition Plant	60-80%
Baltimore, MD	Four Unit Residential housing	76%
Port of Oakland, Ca	Warehouse	70%
Minneapolis, MN	Residential Building	50-75%

4.2. Social benefits

The labor-intensive nature of deconstruction has huge potential in creating jobs for unskilled workers. Unlike demolition, there is no heavy equipment of specific skills required [2,14,17,21]. The current practice of deconstruction is heavily dependent on labor force [2,5,8,11,13,14,17,18,20,21,22,24]. Minorities and "economically disadvantage" individuals can be hired to carry out deconstruction work. In one successful case study, 40% of the workers were women [21]. These individuals were trained prior to engaging in the work and this increases their chance of securing jobs in the construction industry. Deconstruction and DfD have the potential to focus on educational [2], by providing examples to the general public on the building materials reuse and recycling processes, how a new building can use salvaged materials. The maturity of the reused/recycled material market could reduce the cost of building materials and thus benefit society and economy as a whole [2].

4.3. Economic benefits

Aside from the potential savings (e.g. disposal fees, heavy equipment, re-sales value), deconstruction would stimulate the creation of a brand new market for the salvage materials, beyond the existent facilities [4,5]. Great opportunities could also arise from the servicing and facilitation related to DfD, deconstruction, and the recycling and reusing of construction materials. As these practices become popular and well accepted, the benefits would become more obvious. The manufacturing industry would have the opportunities to make their products become easier to disassemble in order to exploit the new market. Webster (2007) defended that "*it is not unreasonable to assume that buildings with DfD features will have greater market value, as well*" [11].

4.4. Other benefits

According to the U.S. Environment Protection Agency (EPA, 2008), "*many buildings slated for deconstruction contain historic materials such as moldings, doors, mantels and other artistic elements that can be used to beautify other buildings and preserve architectural history*"[2]. Historic preservation and Green Building standards are the other reasons to justify deconstruction. Materials' salvage and waste diversion, for instance, will earn credits on green building rating systems such as Leadership in Energy and Environmental Design (LEED), and Green Globes. DfD can also help projects to achieve the Living Building Challenge (LBC) certification. LBC demands the tracking of all building materials to identify potential hazardous components. Although this tracking process is mandatory and highly time-consuming, it is waived for salvaged materials [25].

5. Challenges of 3R and Opportunities for DfD

5.1. Reuse

The uncertainty of the quantity and quality of used materials is quite a disincentive for buyers, due to varying quality and quantity from unreliable sources [2,6,18]. As DfD facilitates deconstruction and creates new market opportunities, the development of large materials yards can be a solution to ensure a more stable supply chain [2].

There is also a lack of rules and standards to regulate the construction with such materials [5,6]. Conversely, the growing of DfD will directly impact the potential improvement of standards and regulations in this area. Through governments and public involvement, building codes and regulations would begin to address issues pertaining to the application of such materials [17].

One of the greatest challenges pertaining to reusing materials is the low demand for such materials [24]. As designers start to use the DfD methods and specify the use of these materials, demand will naturally increase as a consequence. It will further increase if this becomes a widely accepted protocol. Besides, a successful project inspires others and also increases the overall demand for reuse [2].

Other issue is that the damage of materials on-site during deconstruction can make some components unusable [24]. It is caused by erroneous deconstruction methods (due to lack of appropriate training) and/or by structures built without considering the deconstruction process. Besides of a detailed deconstruction plan that facilitates this process, a DfD also requires the jointing methods and the structure itself to be built in such a way to ease the dismantling process [8].

Another challenge is related to consumer tastes: there is a common negative perception of such materials. They are perceived as being inferior in quality compared to virgin materials, both aesthetically and for safety reason [2]. The key for improving the overall perception of reused materials in the market is a growing number of successful show cases. In addition, an improvement of the practice of reused materials' assessment can prove their appropriateness for construction [2].

5.2. Recycle

Recycling facilities are not always located within the vicinity of the construction sites. The transportation of the salvaged materials for reuse and recycling would consume additional energy, time and money, and thus make the process less environmentally and economically friendly [2,16]. The new market created by the advancement in deconstruction will provide opportunities for more recycling facilities. It will consequently shorten the distances between the recycling facilities and the construction sites. One of the steps for a successful DfD is to identify the market opportunities to determine the feasibility of deconstruction for a specific site. According to Dolan et al. (1999), deconstruction is currently more common in the metropolitan areas due to the constant demand for building materials and a large number of deteriorated properties [18].

The lack of information and education is one of the major obstacles to materials recycling [4,10].The designer's role is essential in the education of the general public and stakeholders on deconstruction and recycling, and active marketing could be used as an approach to enhance the community education and awareness on these strategies and their benefits [2].

In addition, quantity and size of building materials, jointing methods that do not ease disassembly and complexity of materials' composition are common challenges pertaining to existing design [10]. Designing new buildings following the DfD principles can overcome the barriers to recycling. DfD requires standard size components, mechanical joint methods (instead of gluing or welding) and materials with simpler compositions that facilitate recycling and reusing processes.

Finally, there are stakeholders-related challenges, such as the lack of experience with recycling methods, inability to identify market for debris, resistance to change, contract formats, and lack of communication between the team [9,18]. By requiring a deconstruction plan and a complete inventory of construction materials, DfD would improve the ability to developing markets for salvaged materials. The detailed planning phase demanded by this design process would facilitate communication of the reuse and recycling of salvaged materials. Government financial incentives would also overcome stakeholders' resistance to change. It is recommended modify contracts provisions for construction [14].

5.3. Deconstruction

Past studies pointed towards the design process as the main hindrance for deconstruction [3,5,6,7,8,9,10]. Buildings are designed without considering the end of life and the process of recovery of these materials. Designers and builders, in general, have conceived their "creations" as being permanent and have not made provisions at the end of their lives [6]. Most designers do not design with an end in mind. Chong et al. (2010) found that the designer was responsible for almost all of the obstacles in the recycling process [10]. EPA (2008) stated that building materials and joints between components have become progressively complex which reduces the recyclability of salvaged materials. If designers do not adopt a sustainable lifecycle approach, reuse and recycling activities will become unfeasible in the future [2]. In addition, Chong et al. (2010) affirmed that designers would have to be at the frontline to ensure that salvaged materials will be reused [10]. Those statements stressed the importance for Design for Disassembly.

Time constraint is another hindrance to deconstruction [2,4,6,13,14,17,18,24]. The time required for disassembly may vary between three to eight times that of mechanical demolition [14]. When time is a critical factor, deconstruction may not be a feasible alternative to demolition. DfD techniques would reduce the time for deconstruction in several ways: 1) establish a pre-planning phase prior to construction; 2) require the proper related documents (plan, inventory, as-built) that ease the deconstruction and the materials recovery processes; 3) provide training to the construction team and helping to increase their productivity [19]; 4) require all construction materials to be labelled; and 5) avoid the use of hazardous materials that consume an extra time during demolition/deconstruction process.

Costs may also be a hinderance to deconstruction [2,4,6,10,14,17,18,21,24]. There is a common perception that cost pertaining to deconstruction is greater than demolition and disposal. However, studies had shown that it is not always true [2,4,6,7,12,13,14,29]. Variables that influence costs include: 1) material storage prior to final destination; 2) higher labor costs; 3) higher costs with workers insurance; 4) transportation of debris; 5) removal of hazardous materials; 6) training expenses; 7) local and regional market and demand for used materials; 8) materials' conditions; and 9) landfill fees. There are also variables that could reduce cost. They include : 1) resales value; 2) partnerships among public, private and non-profit organizations that can help to raise funding and share benefits; 3) financial incentives provided by governments; and 4) savings related to the use of equipments, since in deconstruction activities the only large mechanical equipment often needed is the forklift [4]. The DfD helps to identify market for salvaged construction materials and this increases the resale values [2]. On-site sales can be an alternative to reducing transportation and storage costs. Labor and insurance costs are usually greater for deconstruction, but they can be counterbalanced by saving from equipment use. By avoiding hazardous materials, DfD eliminates the costs pertaining to their removal. In addition, proper training can improve the salvage methods to conserve the quality and conditions of the materials. The Government could act to increase the values of salvaged materials, and reduce landfills' area to increase landfill cost [18], High disposal fees encourage the use of deconstruction, reusing and recycling. Investing in information and education, and also for recycling facilities and legislations are some of the approaches that could potentially make construction recycling and subsequently deconstruction more affordable [10].

Other common challenges faced by deconstruction are contractual issues. Reuse and recycling practices can be less feasible due to traditional contract formats [14]. According to the U.S. Department of Defence (2002), government contracting can be improved by integrating identified barriers and removing them. Federal, State, and local contracting authorities are the ones responsible for removing these barriers [14]. Normally, demolition contracts do not require the materials reuse or recycle, but clauses can be added to address and incentive those practices [14]. Additional time and planning are needed to enhance the contract. As each project is unique, the contractual terms and clauses would have to be developed according to the projects' unique conditions and addressing all issues related to the particular project. The DfD's planning phase requires additional time to develop a comprehensive contractual terms that cover the guidelines of a deconstruction plan. Guy (2000) stated that several contractual options are available [29].

Manufacturers' lack of involvement and responsibility to minimize waste is another challenge to be overcome [2,4,24,28]. It is part of the designer's role to demand manufacturers' involvement and responsibility (e.g., requiring data about the products composition and reusing/recycling methods). The Sustainable Products Purchasers Coalition

(SPPC), for instance, is an initiative based in Portland. The SSPC members use their technical expertise to encourage companies to address Life Cycle Analysis information in their products [28]. Likewise, the Living Building Challenge advises the designers to require manufacturers to label their materials according to their composition. It helps designers to avoid specifying products with hazardous materials and harmful chemicals [25].

Finally, there is a lack of accounting methods for measuring benefits of deconstruction and the recyclability of materials and buildings [4,9,10,16,30]. According to Chong and Hermreck (2009), the lack of appropriate methods causes recycling process to be oversimplified and its costs and benefits cannot be measured in an efficient way. Consistent quantitative studies are still lacking in the deconstruction field [16]. Chong et al. (2010) recommended future studies on the quantification of the relative impacts of the design practices on recycling rates [10]. By studying successful cases of DfD, it may be possible to collect enough data to determine recyclability metric. This metric will help the designer's and owner's decision making to new projects, and hopefully improve the cost-effectiveness of deconstruction. It can also increase and measure deconstruction's environmental positive impacts.

6. Cost-Effectiveness and Feasibility

According to Guy and Ciarimboli (2007), another benefit of DfD is to increase the deconstruction industry's cost-effectiveness through reduction of time and labor requirements [13]. The main variables of deconstruction cost-effectiveness include: 1) building type and composition; 2) labor cost and availability; 3) prevailing disposal costs; 4) availability of salvage markets; and 5) strength of market demand for used building materials [12]. Guy (2000) summarized these variables in the following expression:

(Deconstruction + Disposal + Processing) – (Contract Price + Salvage Value) = Net Deconstruction Costs…. (Equation 1)

where the Salvage Values, that is, the revenues from salvaged materials, were found to be the greater proportion of deconstruction financial return [2,29]. Indeed, authors agreed that cost-effectiveness of a building's deconstruction is influenced by the resales value of salvaged materials and the the disposal savings [4,6,7,29]. The U.S. Department of Defense (2002) also included in this balance the savings with heavy equipment [14]. Chini (2005) affirmed that deconstruction is a cost-effective alternative to demolition [4]. EPA (2008) supported this position and provided results from case studies in which deconstruction proved to be 5% more cost-effective than demolition. Finally, other past experiences suggested that recycling materials could achieve cost savings of U$1 to U$2 per square feet of building area [2].

7. Policy and Partnerships

The economic feasibility of the market for building used materials is tightly dependent on legislative action to create an artificial economic driver [24]. According to Chini (2005), construction related federal laws were focused on energy conservation [4] and did not address recycling activities and reused materials. Some recommendations on public actions include: 1) waiving permit fees for deconstruction and basing permit fees for demolition on the volume of waste generated [29]; 2) development of local resource recovery parks [28]; 3) implementing a grant and award system to create deconstruction incentives [28]; 4) encouraging financial burdens on the landfill process through tipping fees or taxes [24]; and 5) developing an EPR (Extended Producer Responsibility) program in which the original product manufacturer would have the duty to recycle its products and materials at the end of their lifecycle [13,24,28]. In addition, governments themselves should set an example by applying deconstruction techniques instead of demolition, wherever it is feasible [28]. *Design for Reuse Primer*, a Public Architecture's publication, synthesizes the importance of civic buildings as models on sustainability: "These buildings illustrate a commitment to sustainability that can be more concrete than changes in policy" [27].

California has implemented a successful example of such policy. As a state government regulation, it is mandatory that all projects must recycle at least of 70% of their disposal materials [10]. California has become the national leader in recycling, with a widespread network of facilities and contractors throughout the state. Moreover, recycling activities are now easier and economically viable due to the changes in legislation. In Boulder, Colorado, there is a mandatory Green Points program that encourages and provides credits for deconstruction, recycling and reuse of building materials. The King County in Washington, through its Solid Waste Division, stimulates deconstruction activities by providing online tools and resources, including DfD guidelines and specifications. The state of Massachusetts also followed similar example, through, an amendment of the state's waste disposal regulations that prohibits the landfilling of asphalt pavement, concrete, metal, and wood wastes., This represents a large incentive to reuse and recycling activities in the local construction industry [2].

In conclusion, many authors agreed that partnerships (i.e., between governments, private sector, non-profits, historical societies, and other organizations such as Habitat for Humanity) are the best option for deconstruction's cost effectiveness and overall success [2,4,6,17,18,21]. Chini et al. (2001) summarized the important of partnerships: "successful implementation could not occur without a support structure of government, regulations, and businesses working together toward a joint goal" [6].

8. Conclusions and Future Research

Through case studies and qualitative research, deconstruction would be a feasible alternative to demolition given the right regulations and markets to be in placed first. The main challenges in deconstruction implementation can be overcome by the opportunities created by DfD, public involvement and successful partnerships. As future efforts for this research, quantitative data on building materials' reuse, recycling and deconstruction activities will be collected and analyzed. The objective is to contribute to establish metrics to building's reusability and recyclability. These metrics can be used in building codes and government subsidies that aim to incentive deconstruction activity, by establishing recyclability goals for new buildings, for instance [26]. Besides, once these metrics are well established, construction industry's stakeholders will have a more solid basis for decision-making process regarding deconstruction and Design for Disassembly.

8. References

[1] G. Augenbroe, A.R. Pearce, Sustainable Construction in the United States of America: a perspective to the year 2010, Georgia Institute of Technology, 1998.

[2] U.S. Environment Protection Agency (EPA), Lifecycle Construction Resource Guide, Atlanta, 2008.

[3] C.J. Kibert, Sustainable Construction: Green Building Design and Delivery, third ed., John Wiley & Sons Inc. New Jersey, 2013.

[4] A.R. Chini, Deconstruction and Materials Reuse – an International Overview, University of Florida, 2005.

[5] C.J. Kibert and A.R. Chini, Overview of Deconstruction in Selected Countries, University of Florida, 2000.

[6] C.J. Kibert, A.R. Chini, J. Languell, Deconstruction as an Essential Component of Sustainable Construction, University of Florida, 2001.

[7] B. Guy, S. Shell, Design for Deconstruction and Materials Reuse, in A.R. Chini & F.Schultmann, Design for Deconstruction and Materials Reuse: Proceedings of the CIB Task Group 39 – Deconstruction Meeting, CIB World Building Congress, Wellington, New Zealand, 2002.

[8] M.D. Webster, D.T. Costello, Designing Structural Systems for Deconstruction: How to extend a new building's useful life and prevent it from going to waste when the end finally comes, Greenbuild Conference, Atlanta, 2005.

[9] L. Liu, Tracking the Life Cycle of Construction Steel: the development of a resource loop, Univeristy of Kansas, 2009.

[10] I. Srour, W.K. Chong, F.Zhang, Sustainable Recycling Approach: An Understanding of Designers' and Contractor's Recycling Responsibilities Throughout the Life Cycle of Buildings in Two US Cities, University of Kansas, 2010.

[11] M.D. Webster, Structural Design for Adaptability and Deconstruction: a strategy for closing the materials' loop and increaing building's value, New Horizons and Better Practices, 2007.

[12] NAHB Research Center, Inc., Deconstruction – Building Disassembly and Material Salvage – The Riverdale Case Study, Maryland, 1997.

[13] B. Guy and N. Ciarimboli, Design for Disassembly in the Built Environment: a guide to closed-loop design and building, Pennsylvania State University, 2007.

[14] U.S. Department of Defense, Selection of Methods for the Reduction, Reuse, and Recycling of Demolition Waste, 2002.

[15] W. McDonough, M. Braungart, Cradle to Cradle: remarking the way we make things, first ed., North Point Press, 2002.

[16] W.K. Chong, C. Hermreck, Understanding transportation energy and technical metabolism of construction waste recycling, 2009

[17] NAHB Research Center Inc., A Report on the Feasibility of Deconstruction: an investigation of deconstruction activity in four cities, U.S. Department of Housing and Urban Development, Washington, 2001.

[18] P.J. Dolan, R.G. Lampo, J.C. Dearborn, Concepts for Reuse and Recycling of Construction and Demolition Waste, US Army Corps of Engineers, 1999.

[19] B. Hamidi, T. Bulbul, A Comparative Analysis of Sustainable Approaches to Building End-of-Lifecycle: Underlying Deconstruction Principles in Theory and Practice, Virginia Polytechnic Institute and State University, 2012.

[20] A.R. Chini, S. Bruening, Deconstruction and Materials Reuse in the United States, University of Florida, 2003.

[21] S. Walker, Deconstruction Works, Materials for the Future Foundation, San Francisco, 2001.

[22] Franklin Associates, Characterization of Building-related Construction and Demolition Debris in the United States, Kansas, U.S. Environmental Protection Agency, 1998.
[23] B. Guy, The Optimization of Building Deconstruction for Department of Defense Facilities: Ft. McClellan Deconstruction Project, Journal of Green Building, 1998.
[24] S. Nakajima, M. Russel, Barriers for Deconstruction and Reuse/Recycling of Construction Materials, University of New Mexico, 2014.
[25] Living Future Institute, Living Building Challenge^{SM} 3.0: Materals Petal Handbook, 2014.
[26] C. Thormark, Assessing the Recycling Potential in Buildings, in A.R. Chini, Design Deconstruction and Materials Reuse – Technology, Economic, and Policy: Proceedings of the CIB Task Group 39 – Deconstruction Meeting, CIB World Building Congress, Wellington, New Zealand, 2001.
[27] L. Ogbu, Design for Reuse Primer, Public Architecture, 2010.
[28] B. Milani, Building Materials in a Green Economy: Community-based strategies for dematerialization, University of Toronto, 2005.
[29] B. Guy, Building Deconstruction: Reuse and Recycling of Building Materials,University of Florida, 2000.
[30] A. Akbarnezhad, K.C.G. Ong, L.R. Chandra, Z. Lin, Economic and Environmental Assessment of Deconstruction Strategies Using Building Information Modeling, National University of Singapore, 2012.