Diversion Dynamics: A Process-Based Approach to Deconstruction Analysis

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This paper presents a deconstruction analysis approach which focuses on mapping variations in landfill diversion rates throughout the course of onsite operations. The methodological foundations of the approach are described and a study of a recent deconstruction case is presented in order to demonstrate practical applications. Lastly, challenges, opportunities, and future developments are discussed.

INTRODUCTION

Deconstruction is often described in literature as a systematic and organized alternative to demolition, one which is predominantly motivated by an effort to maximize landfill diversion rates through increased reuse and recycling[1]. In such definitions, these sources seem to perceive demolition and deconstruction as directly comparable practices, mainly due to the fact that both are short-term interventions guided by the intention of clearing a building site for new construction. Consequently, a similar set of metrics is typically used to measure success in both demolition and deconstruction activities: Cost, rate of building mass removal, and a total sum of reuse, recycling, and disposal quantities. In practice, however, deconstruction substantially differs from demolition in many aspects, most notably in its duration and the type of onsite operations it requires. While full demolition and site clearing of an average 1600 square foot single story residential building, for example, would normally take only 3 days, full deconstruction of the same asset would take an average 2.4 weeks[2]. This considerable difference can be attributed to the manual and more meticulous nature of deconstruction as opposed to the mostly mechanized nature of demolition. It would, therefore, be insufficient to analyze deconstruction based only on its final outcomes. Deconstruction should be viewed and measured as an extended process, characterized by complexities which are more analogous to construction rather than demolition. A process-based approach to deconstruction analysis would not only allow accurate depiction of the progress of diversion rates throughout the course of onsite operations, but would also assist in detecting problematic steps and techniques in a manner beyond the capabilities of a final diversion rate account.

To cope with these challenges, the analysis strategy proposed in this paper focuses on dynamic documentation of diversion rates throughout the deconstruction process, assessing recovered quantities through the lens of influencing factors such as assembly and material categories, tools used, and connection types. In the following pages, the methodological foundations of the strategy are presented, followed by a demonstration of the method on a case study featuring a recently deconstructed research facility. The paper concludes in an examination of the results and proposes future research directions.

METHODOLOGY

In essence, the diversion dynamics analysis approach recognizes the logic behind total diversion rate accounting as the widely accepted evaluation metric for recovery efficiency. However, since it supports a view of deconstruction as a sequence of diverse operations, each yielding varying amounts of recovered materials, the method seeks to examine diversion rates on a timeline rather than as a single final outcome. In addition to time, the method also maps diversion fluctuations based on three performance attributes: Material type, connection type, and tool type. In presenting diversion rate dynamics from four different perspectives, the method aims at providing a multi-layered image of deconstruction efficiency, one that could provide insights regarding challenges and opportunities presented by specific operations and decision points throughout the entire process.

In addition to typical background information regarding the studied project and the methods used to collect data, a diversion dynamics analysis process would also consist of the following components: First, a detailed description of the onsite sequence of deconstruction operations. Such description is used to support a timeline analysis of diversion metrics at a later stage in the process. Second, an overview of the various tools used during the deconstruction process. This description can then accompany an examination of the connection between diversion rates and the type of tools used. Third, it would include an account of the duration of onsite deconstruction operations. Fourth, a summary of prevalent connection types in the project. These connection types are then tied to diversion rate findings in order to identify problematic connection strategies from a recovery standpoint. Fifth, a general diversion rate is calculated and presented. Finally, a breakdown of the general diversion rates by time, material type, connection type, and tool type is shown and conclusions are drawn regarding local challenges and opportunities throughout the deconstruction process.

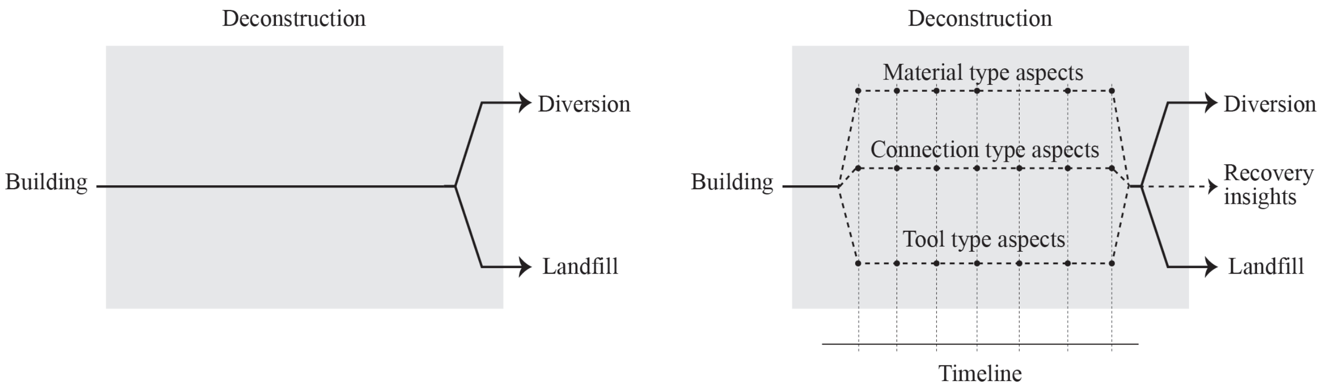

Figure 1: Typical approach to deconstruction evaluation in surveyed literature (left) and a process-oriented approach.

APPLICATION:
THE SNYDER EQUINE RESEARCH FACILITY AS A CASE STUDY

In the following pages, the methodology presented above is further articulated and tested through a study of a recent full deconstruction case. The documented building is a 5,388 ft2 equine research facility at the University of Georgia (UGA) in Athens, GA. It is important to note that full deconstruction of buildings larger than a single family home is relatively uncommon, mainly due to the unique challenges presented by large scale to a practice which is usually mostly manual. Although untypical, deconstruction of non-residential buildings makes a useful case study as it underscores some of the major problematic domains in deconstruction practice:

1. Access: While small ladders are typically sufficient for house-scale full deconstruction, larger buildings often require increasingly complex access solutions.

2. Disassembly of primary structure: Disassembly of structural building components is a challenging task regardless of scale; however due to the size and weight of members in larger-scale buildings, the removal of supporting beams and columns is particularly difficult.

3. Handling of large building components: Large buildings often include components which can pose substantial maneuvering difficulties.

4. Disassembly time: Naturally, the larger and more complex a building, the longer it takes to deconstruct it. Additionally, deconstruction time becomes extremely problematic in public buildings since the project schedule is typically tight and demolition is often the more available, faster, and cheaper alternative.

BACKGROUND

Built in 1978 at a construction cost of about $76,000, the Snyder research facility was operated by the Equine Program at the College of Agricultural and Environmental Sciences at UGA. The facility was primarily used by the program's reproduction research team and was designed to house 50 horses (mostly broodmares) as well as a small group of researchers and instructors. In the early 2000's, it has been decided to remove the Snyder facility in order to give way to a new veterinary medical learning facility to be operated by UGA's College of Veterinary Medicine. The new facility was constructed more than a decade later, in 2015. The university's Material Reuse Program was charged with deconstructing, reselling and reusing the Snyder facility components. The deconstruction process took place in two phases. The first phase included removing around 20 acres of vinyl fencing west of the facility structures. The second phase, which is the subject of this case study, included the full deconstruction of the facility's main structure. The primary structure consisted of a light timber-frame assembly, cladded by a thin layer of Styrofoam and painted aluminum exterior siding.

The building had a number of ideal attributes for high quality material recovery: First, since most of the spaces were designed primarily for livestock, there was very little flooring. This made access to subterranean components such as foundations and sewage systems easy, clean, and quick. Secondly, almost all of the materials used were untreated and uncoated, making many of the components excellent candidates for recycling. The painted aluminum siding was the only major component to contain coating, although there are well developed technologies for full recycling of painted aluminum[3]. Thirdly, many of the more complex components in the building such as the main roof trusses and all of the

Figure 2: The Snyder facility: Aerial view and view from the south

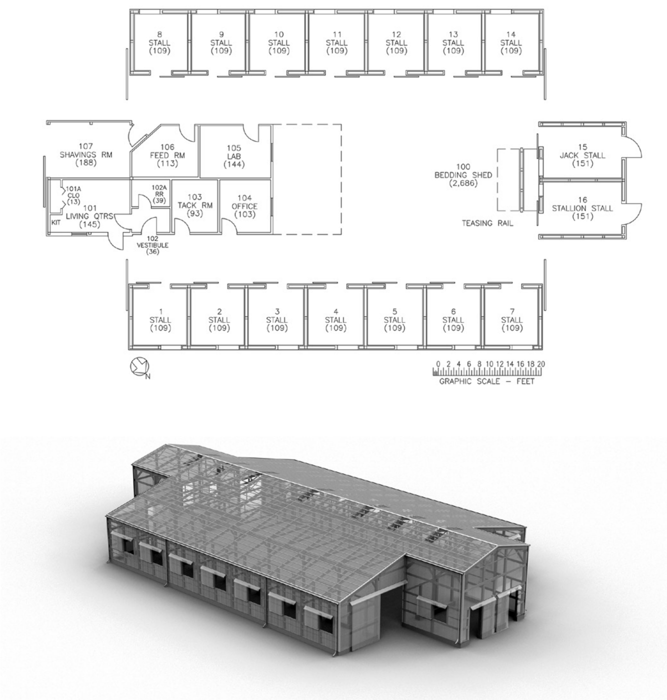

Figure 3: Floorplan and overview of envelope and primary structure (floorplan source: The University of Georgia Engineering Department).

window assemblies could be fairly easily removed from the building in one piece to be sold for reuse or to be further disassembled off-site. Lastly, there were almost no interior design components and much of the structure is exposed, making access to major components easier.

DATA COLLECTION

Research activities in the Snyder equine facility case involved the following items: A) Plans of the structure obtained from UGA's Engineering Department. B) Continuous presence on site throughout the deconstruction process. This included the study of deconstruction operations through observation and partaking in dismantling activities. UGA's policy regarding deconstruction grants access to a structure under deconstruction only to university employees and affiliates. Due to this policy, the author's participation was limited to disassembly of components after their removal from the primary structure. These components included shutter and door assemblies, as well as roof components. C) Weighing and physical measurement of salvaged components. Landfill diversion rates were calculated by weighing all components retrieved from the structure. Smaller components were weighed on site using a Fairbanks Morse 1280A portable platform scale. Large component sets, such as aluminum siding segments, were weighed at an adjacent Fairbanks truck scale. Due to the lack of machinery needed in order to handle heavy components, the concrete foundations of the structure were not weighed. Instead, their approximate weight was calculated based on their geometry and typical concrete density. These are the only significant components not to be physically weighed during the study. D) Sequence documentation through photography. Photos from various angles were captured every few hours throughout much of the deconstruction process in order to be able to follow the specific order in which various component layers were removed from the building. Analysis of these series sheds light on successful and problematic deconstruction practices, as well as on possible measures required to improve performance. E) 3D modeling of the deconstruction sequence. Detailed modeling of the structure and the observed sequence of operations was carried out in order to better understand system-scale challenges which possibly remained unnoticed on site.

ANALYSIS

Spanning approximately two weeks, the deconstruction process consisted of two general phases: The first, lasting around one week, focused on removal of all building skin components. This included wall and roof siding, insulation, skylights, windows, and doors. Interior asbestos abatement activities on a limited scale took place during this phase as well. The second phase focused on disassembly and removal of all structural components, including cast-in-place concrete foundations, posts, beams, roof trusses, wall studs, and roof purlins. Prior to these two phases, the building underwent an interior gutting process which is not discussed in this study since it primarily involved the removal of furniture and appliances, constituting a small fraction of all deconstruction activities on-site and associated recovered material quantities. The vast majority of subassemblies were taken apart down to their respective components while still attached to the primary structure. The only subassembly groups to be taken apart after being detached from the primary structure (whether on the building site or off it) were the sliding window shutters, doors, and main roof trusses.

Tools

It might be surprising to learn how limited and basic the range of tools required to take an entire building apart. From a tooling perspective, the deconstruction process can be divided into two phases: Manual deconstruction and machine-aided deconstruction. Most of the sequence described above was carried out using simple hand-held tools. Up to step 18, the deconstruction crew used the following tools: Claw hammers, flat bars, wrecking bars, cordless electric screwdrivers, and ladders. From step 18 on, much of the deconstruction and debris removal work was done with the aid of a Genie GTH-644 telescopic forklift and a 35D John Deere excavator. Both are compact construction and handling vehicles. This machinery was primarily brought in to overcome component maneuvering challenges. Although most of the structural roof components were light enough to be carried by two individuals, some of the components which needed to be removed whole (such as the trusses) were simply too large to maneuver manually. Given more onsite time and the option to deconstruct the roof trusses rather than removing them whole, the entire process could have been carried out manually.

Deconstruction Sequence

Prior to commencing any deconstruction activity on site, power supply was cut off to the building and any flammable or hazardous content was removed. The only exception was some asbestos-based flooring in the office areas, which was removed shortly after onsite activities began. Excluding interior gutting operations, deconstruction efforts on the

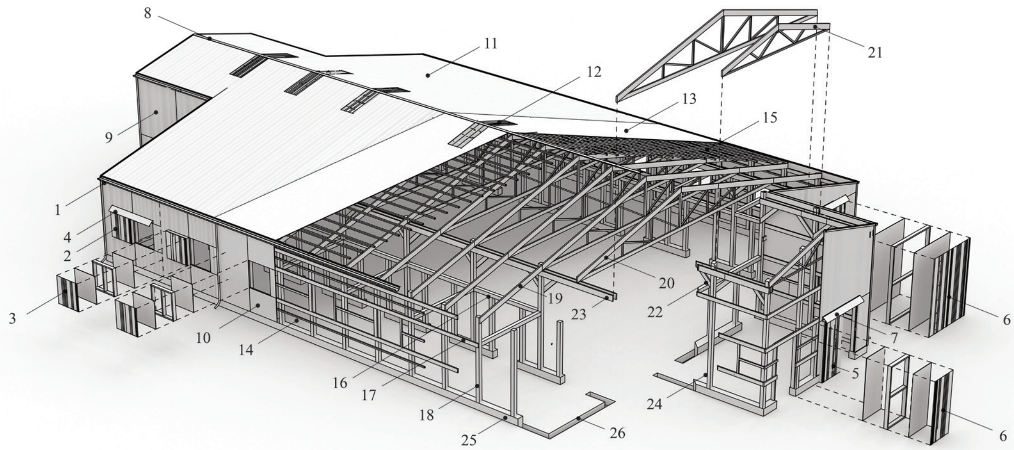

Figure 4: Snyder facility deconstruction sequence: 1. Gutter removal. 2. Sliding shutter subassembly removal. 3. Sliding shutter disassembly. 4. Sliding shutter track and window cap flashing removal. 5. Sliding door subassembly removal. 6. Sliding door disassembly. 7. Sliding door rail and flashing removal. 8. Siding trim and roof fascia removal. 9. Exterior siding removal. 10. Wall insulation removal. 11. Roof panel removal. 12. Roof skylight removal. 13. Roof insulation removal. 14. Secondary bent girt removal. 15. Purlin removal. 16. Primary bay girt removal. 17. Primary bent girt removal. 18. Outer rafter removal. 19. Bent post removal. 20. Roof truss removal. 21. Roof truss reuse. 22. Bay post bracing removal. 23. Bay plate (main beam) removal.24. Bay post removal. 25. Foundations excavation and removal. 26. Site treatment.

Snyder facility structure can be broken down into 26 general steps in chronological order (see Figure 4).

Duration

The duration of onsite presence was largely guided by the schedule of construction activities of the future veterinary medicine campus. UGA authorities originally opted for demolition of the Snyder facility. Although demolition would have been far more costly than deconstruction, it promised a much shorter evacuation schedule. Permission to deconstruct the building was eventually granted to the university's reuse program as long as the site would be cleared within a limited amount of time. The most problematic building component in terms of disassembly time was the exterior wall siding. Initially estimated to take 2-3 full days of onsite work, the siding (both wall siding and roof panels) eventually took around 10 days to be completely removed. This long disassembly time had mainly to do with the vertical siding connection strategy. The components removed within the shortest amount of time were the rigid insulation sheets which lined both the walls and the roof. These sheets were removed quickly mostly due to being a loose laying layer located in-between the siding and its supporting structure.

Connection Type

As implied above, connection types proved to play a significant role in determining the effort needed to take components apart, the time it took and the condition of each component after its removal from the building. The most compelling example of the importance of connection types could be observed through the difference between wall siding and roof panel removal. Although both were made from the same material with identical processing (corrugated aluminum sheets), the roof panels were removed much faster and in far better condition. This was due to the connection types used: In the roof, all panels were attached to the supporting timber structure using reversible steel screws while in the wall, siding was attached to the structure using long timber nails. Denailing the wall portion of the building required considerable physical force using a flat bar or a wrecking bar, took between 10-30 seconds per nail, and resulted in significant damage to the removed components. The damage to the removed siding components was so extensive that it ruled out any possibility of reuse. In comparison, the screws used to attach the aluminum roof panels were removed in under 5 seconds per screw using an electric cordless screwdriver. Their removal was not only faster and required less effort; it also left the components in reuse-ready condition and retrieved fully reusable screws. Furthermore, far fewer

Figure 5: Selected time-lapse photos illustrating different stages in the deconstruction sequence: View from the north

screws were used to attach the roof panels than nails used to attach the wall siding, possibly due to the higher cost of screws and the lower level of automation in installing them (screwdriver versus nail gun).

Diversion Rates

The next page shows an account of total diversion rates per component and material group. Landfill diversion rates are defined as the sum of reuse and recycling rates. Calculation of the total diversion rates for the project indicates that over 88% of the 88,052.1 pounds (39,939.8 kg) of components and materials removed from the site were diverted from landfills to be reused or recycled. Since the economic feasibility of the project depended to a large extent on the amount and condition of components salvaged for resale, the project yielded around 84% reuse rate, far greater than the national average diversion rate (33.8% in 2010)[4]. From a material standpoint, only composites (in this case, skylight and insulation components) were found entirely unsuitable for recycling or reuse. The relatively high reuse rates by weight were largely achieved due to UGA's ability to put all the salvaged concrete footings into full use in campus landscape projects. From a connection type perspective, components joined by reversible connections were found more suitable for reuse purposes and the use of irreversible connections seems to increase the likelihood of recycling as an end-of-life solution. Reversible connections were considered those which allowed removal of a component from the building with relatively minor to no damage to it in the process: Loose (for insulation sheets), bolts, screws, and soil (for cast-in-place concrete footings). Nails and chemical binders were considered irreversible connection types in this study.

Component	Qty.	Material group	Notes	Reuse (lb)	Recycling (lb)	Waste (lb)
Siding	NA	Metals	Aluminum (painted)		1342.4	
Roof panels	NA	Metals	Aluminum (uncoated)		2013.6	
Shutter tracks	14	Metals	Steel pipe	217		
Window L brackets	28	Metals	Steel	841		
Other L brackets	60	Metals	Steel	256		
Bracket connection	28	Metals	Steel	56		
Screws	NA	Metals		86		
Posts and beams	NA	Lumber	2X4/2x6/2x12/4x6/6x6	33640		
Posts and beams	NA	Lumber	Too short for reuse			381
40' Trusses	13	Lumber	Sold for reuse	4420		
40' Trusses	2	Lumber				680
24' Trusses	3	Lumber	Sold for reuse	300		
24' Trusses	1	Lumber				100
Plywood sheathing	28	Lumber	Window subassembly	308		
Window jambs	14	Lumber				252
Footings	5	Concrete	6x24x93 Inch	5812.128		
Footings	32	Concrete	6x24x65 Inch	25998.336		
Footings	4	Concrete	6x18x65 Inch	2437.344		
Skylights	14	Composites	GFRP (fiberglass)			70
Insulation	NA	Composites	0.75" Styrofoam			8841.3
			Total (lb)	**74371.8**	**3356.0**	**10324.3**
			Total (%)	**84.46**	**3.82**	**11.72**

Table 1: Diversion rate distribution by weight.

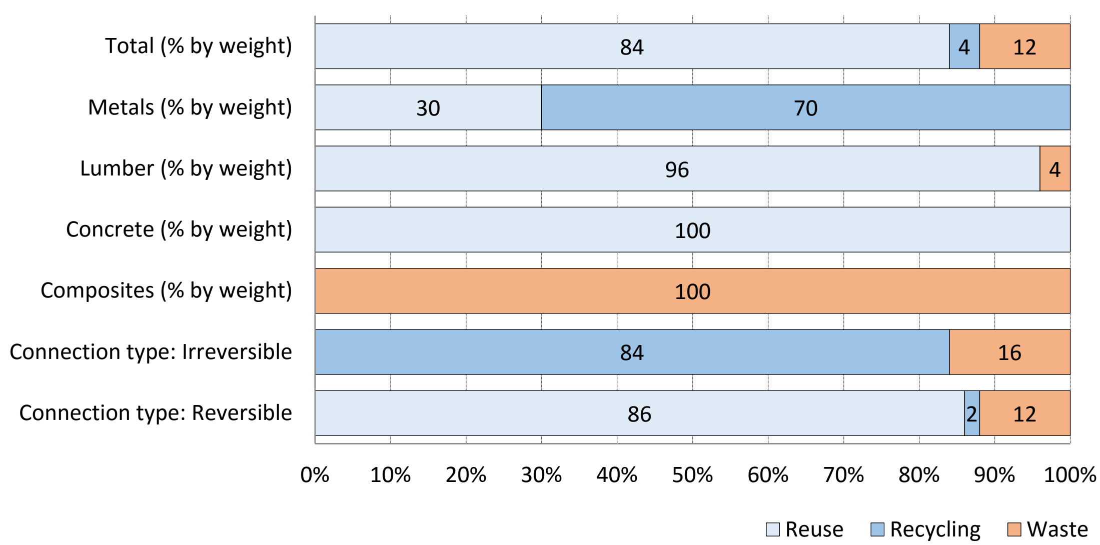

Table 2: Diversion rate distribution (%) by material group and connection reversibility.

FINDINGS

Plotting the variation in recovery rates per stream type (reuse, recycling, and waste), material group, connection reversibility, and tool category along the deconstruction sequence specified earlier suggests a number of recovery trends (in the graphs below, please note that the vertical axes are on a logarithmic scale):

Table 3 indicates that: A) the removal of components designated for recycling concentrates in a relatively small number of steps during the early stages of the deconstruction process. All recycling-bound components were removed between steps 8 and 11, which included the building's roof and wall siding. B) Most of the landfill waste was generated between steps 10 and 13, which included all the envelope insulation foam and the GFRP skylight panels. C) While components for reuse were retrieved throughout both the early and late stages of the deconstruction process, most reuse content by weight was generated during the disassembly of the timber structure (steps 14 to 20) and during the excavation of the concrete footings (step 25 to 26).

Table 4 indicates that: A) there is a clear correlation between material groups and the distribution of stream types described in table 3. Metals correspond with reuse and recycling streams, composites correspond with waste streams, lumber corresponds with both reuse and waste, and concrete footings correspond in this project with reuse. B) There is also a clear correlation between material groups and the chronology of deconstruction. Metals were removed early in the process, followed by composites, lumber and finally concrete. This is mainly due to the roles these materials groups played in the structure of the Snyder facility: Metals made up much of the skin, lumber made up both the envelope structure and the primary structure, composites made up the insulation, and concrete made up the foundations.

Table 5 indicates that most of the components in the building, both by weight and by deconstruction sequence steps, are characterized by some degree of connection reversibility, a fact which undoubtedly assisted in achieving high recovery rates. It should be noted, however, that although only a small number of deconstruction steps are associated with irreversible connections, they refer to a major part of the building: its entire external wall siding.

Table 6 indicates that the introduction of vehicle and machine-aided deconstruction operations around step 15 help yield larger amounts of recovered materials from that point on until the final steps of the process. Clearly, this specific depiction is influenced in part by the use of weight as a diversion metric. A use of market value instead, for example, might result in a different interpretation.

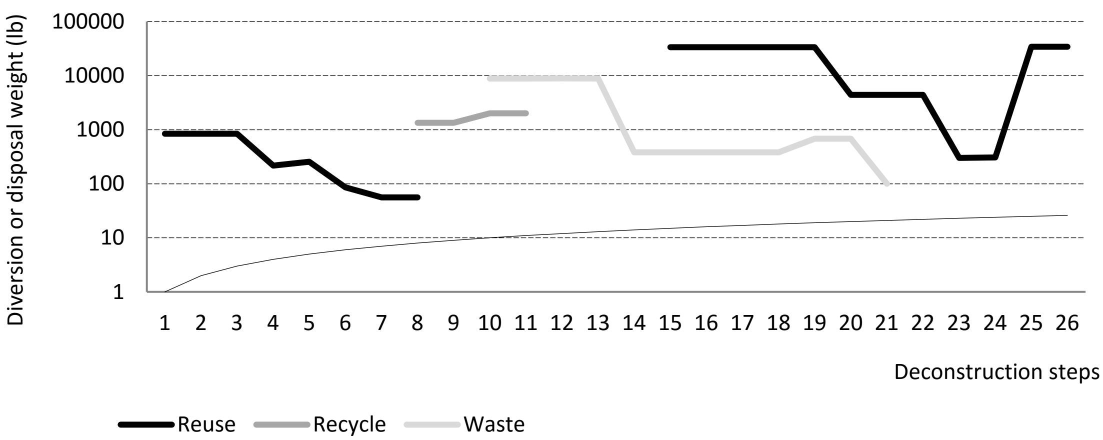

Table 3: Diversion rate variation based on stream type and deconstruction step.

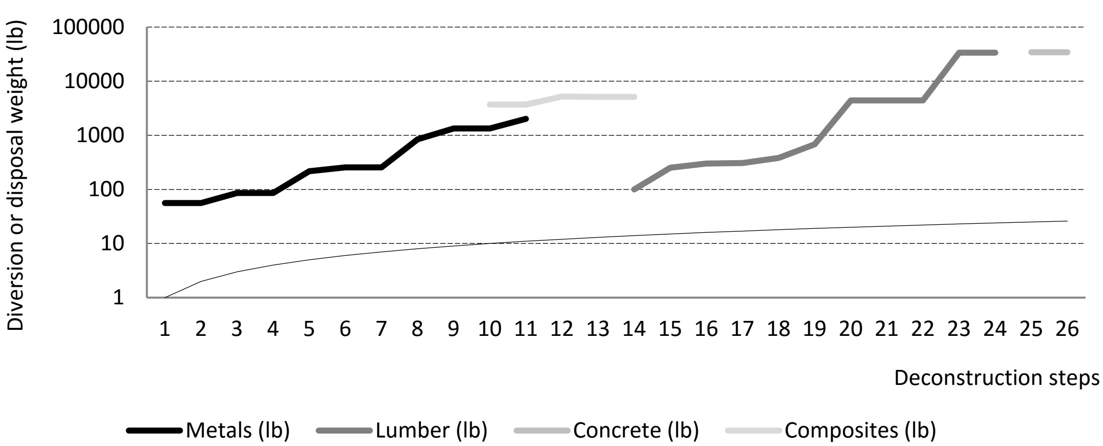

Table 4: Diversion rate variation based on material group and deconstruction step.

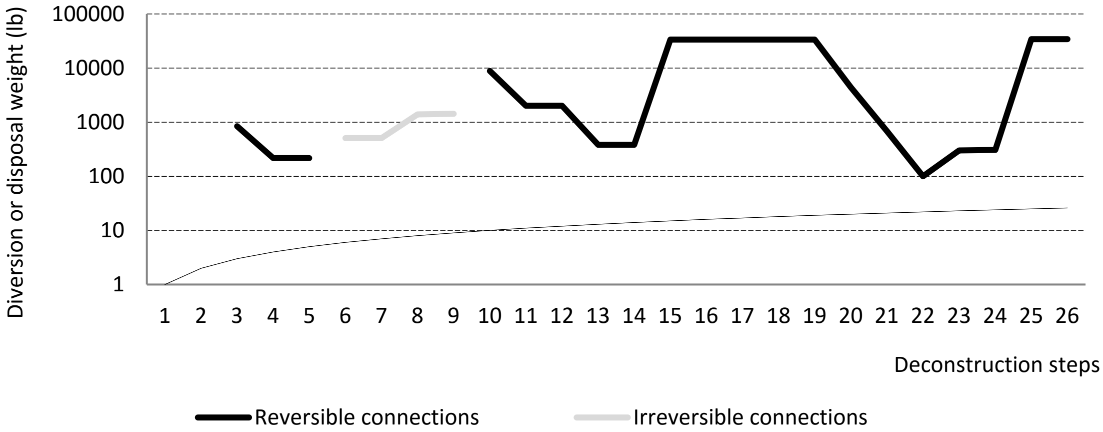

Table 5: Diversion rate variation based on connection reversibility and deconstruction step.

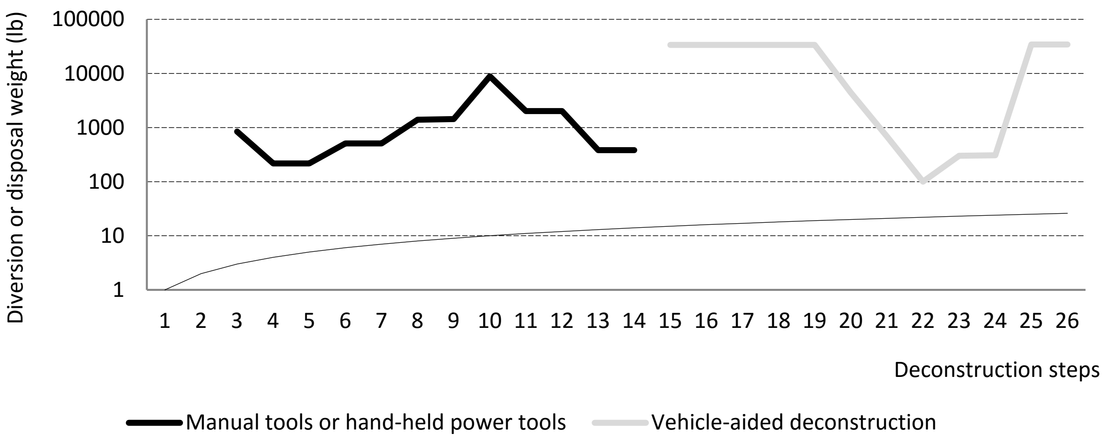

Table 6: Diversion rate variation based on tool category and deconstruction step.

DISCUSSION

A consideration of the diversion patterns illustrated in the graphs above, along with the information presented regarding this case, offers a number of valuable insights concerning challenges and opportunities in the Snyder facility project as well as more broadly in deconstruction as a practice.

A. Time-related challenges: The duration of onsite operations can be tied in this project, as is the case in many other deconstruction projects, to the type of tools used, the reversibility of connections between components, and a need (or lack thereof) to avoid damage in order to preserve salvaged components in reusable condition. In the Snyder case, for example, one could identify that the combination of manual tools and predominantly irreversible connections in steps 7 to 9 may require considerable time and result in major schedule setbacks, as was indeed the case in practice. A process-based assessment approach can assist in detecting delay-prone steps in such cases during the planning phase of a deconstruction project.

B. Economic challenges: Although the analysis presented so far does not directly discuss economic considerations in deconstruction, the findings can provide some insights into this field as well. Since deconstruction professionals typically rely on the sale of salvaged components and materials as a primary source of funding, one could expect to see a direct connection between reuse rates and the existence of other sources of funding (government support for example). Lower reuse rates would reflect less attention to maximizing resale potential and would indicate the possible existence of alternative funding sources. Consider, for example, a comparison between the Snyder case diversion rates and those of the Riverdale case study conducted by the American National Association of Home Builders (NAHB) for the USEPA in 1997.

Both projects are of similar size and materiality, although admittedly, the Riverdale case presents further deconstruction complexities being a housing project. One significant difference between the two projects is that the Riverdale deconstruction project primarily relied on external funding from the Department of Housing and Urban Development (HUD) regardless of any additional income from salvaged material sales[5], while the Snyder deconstruction project relied on resale as an only way to generate funding for the continued operation of UGA's material reuse program. This distinction, among other factors, resulted in reuse rates of only 23% for the Riverdale project while the Snyder case reached reuse rates of about 84%. From an economic standpoint, a process-based assessment can increase reuse rates by locating problematic steps and processes early in the planning of a deconstruction project. Needless to state, good design can also play a major role in increasing end-of-life reuse and material recovery rates.

C. Technological challenges: Recycling rates in a deconstruction project depend to a large extent on the availability of appropriate recycling technologies. As can be seen in table 3 and table 4, there is a clear correlation between the content designated for recycling in the Snyder project to a single material group: metals. Although it may be motivated by an interest in maximizing reuse rates in the project, the exclusive recycling of metals may also be a result of lack of adjacent recycling facilities for other material groups such as timber and concrete. A process oriented approach can identify such challenges early in the process aid in comprising a comprehensive material recovery management plan.

D. Sequence challenges: As table 3 suggests, most of the components retrieved for reuse purposes were salvaged from the building relatively late in the deconstruction sequence. During the first 10 days or so of the process, the vast majority of materials removed from the building were recycled or discarded. Typically, one would expect a reverse order of diversion quality: Delicately removing components for reuse while the site is clean and the deconstruction crew is focused followed by removal of components for recycling and eventually disposing of components unfit for recovery. Although much of the sequence is typically predetermined by early design decisions, a process oriented approach to deconstruction planning can assist in finding an optimal recovery solution for a given set of circumstances.

E. Connection type challenges: Although, as table 5 shows, only a small number of deconstruction operations had to negotiate irreversible connections, those operations took much longer than expected and resulted in considerable damage to the materials salvaged. While it is difficult to avoid the challenges presented by detaching large portions of heavily nailed surfaces, the use of a process oriented evaluation can aid in reaching a more realistic time estimate for these specific steps in a deconstruction sequence.

F. Tool and access-related challenges: As can be observed in table 6, tool type, component location within the structure, and its handling dimensions played a key role in the amount and speed of material recovery in the project. While simple manual tools provided flexibility and ease of access in the early stages of the deconstruction process, they were also significantly slower in unfastening mechanical or fixed connections. Similarly, although the construction vehicles introduced around step 15 expedited the deconstruction process and allowed relatively effortless handling of large structural components, they may have lacked the precision required to remove frail components designated for reuse. The use of a process oriented approach can aid in balancing the advantages and drawbacks of different tool types and determine optimal points in the process to introduce or avoid the use of certain tools and machinery.

In conclusion, analyzing and measuring deconstruction as an evolving process rather than through a single final result can reveal significant insights regarding the use of certain materials, connection types, and tooling as influencing factors on recovery rates and landfill diversion efforts. It should be stated that the methodology and implementation strategies proposed in this paper are presented as a basis for further development and discussion, rather than as a finalized evaluation package. Future work in this field should aim for added precision in the analysis of patterns and processes, as well as a rigorous step-by-step data collection plan during all stages of onsite deconstruction operations.

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ENDNOTES

1. Smith, Eddy, Mr William E. Boone, and Mamar Shami. "Sustainable Approaches to Landfill Diversion: The Global Sustainability of Deconstruction." In Proc. Int. Conf: Sustainable construction materials and technologies, vol. 1. 2007.
2. Dantata, Nasiru, Ali Touran, and James Wang. "An analysis of cost and duration for deconstruction and demolition of residential buildings in Massachusetts." Resources, conservation and recycling 44, no. 1 (2005): 1-15.
3. Kvithyld, Anne, C. E. M. Meskers, Sean Gaal, Markus Reuter, and Thorvald Abel Engh. "Recycling light metals: Optimal thermal de-coating." JOM 60, no. 8 (2008): 47-51.
4. District of Columbia's Green Dashboard, "Waste Diverted from Landfills: National Landfill Diversion Rate Average", http://green-dashboard.dc.gov/Waste/WasteDivertedFromLandfills, 2013.
5. Deconstruction, Building Disassembly and Material Salvage: The Riverdale Case Study. NAHB Research Center, 1997.