Determining a Building's Residual Value: How Construction, Transformation, and Deconstruction Techniques Can Enhance Value

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This paper examines how construction, transformation, and deconstruction techniques influence a building's residual value, proposing a Design for Assembly and Disassembly (DfAD) method to assess reuse potential. By highlighting gaps in current circularity assessments and financial practices, the paper shows how better design and planned disassembly can support multiple life cycles.

Although not produced within the **Drastic** project, the research aligns with Drastic's ambition to support multi-cycle design and evidence-based circularity. The DfAD method complements Drastic's Multi-Cycle Sustainability and Circularity Assessment Framework by offering a design-phase approach that helps assess reuse potential and improve decision making around material retention.

The connection to Drastic is strengthened by the involvement of project partner **Produktif**, who authored this research paper and co-lead Drastic's Nordic Demonstrator. Produktif's involvement ensures that insights from this research can inform Demonstrator activities and contribute to Drastic's broader effort to advance circular, multi-cycle building solutions.

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Abstract. The need for improved financial models for assessing building value in a circular economy has been recognized for years [1]. In particular, financial institutions using either the business case approach or the collateral approach when financing a construction project must assess the overall environmental impact of a building throughout its lifecycle. In both approaches, an important element of that financial calculation has traditionally been the determination of the residual value of what was being financed. For a building loan, the residual value would be based on the materials that are recycled or refurbished and incorporated into a second-generation building. The construction transformation and deconstruction techniques can affect the residual value of the site or any remaining building structure. The research question addressed in this study is to identify and assess building construction, transformation, and deconstruction approaches that maximize a building's residual value. This study includes a survey of banks to determine the methods currently used for establishing residual values and proposed enhancements to those methods. It also includes a literature search and review of building construction, transformation, and deconstruction methods for evaluating materials and labor costs. These techniques should maximize residual value at the end of a building's life enabling multiple building lifecycles.

Keywords: Circular economy, Residual value, Construction.

1 Introduction

The foundational concept of a circular economy is economic activity that conserves natural resources. This concept applies to every industry and reflects the principles of wise management of natural resources. Governmental entities such as the European Union have established regulations and a taxonomy for implementing a circular economy. Included in that taxonomy are regulations and guidelines for all commercial and industrial sectors.

The construction industry has been slow to adopt the mindset of a circular economy [2]. The construction industry accounts for one third of waste and carbon emissions. In addition, the construction industry has not embraced new business models or technical innovations that would improve circularity. Previous studies have shown that this is due in part to the lack of incentives to change behaviors [2]. One aspect of the industry that could provide incentives to change is the lending market. If financial institutions required a robust assessment for circularity before providing financing for construction projects, architects, engineers, and builders would be more likely to include circularity principles in the design and construction of buildings. However, there are few tools or techniques that can be used by a financial institution to evaluate the circularity aspects of a construction project. Most institutions just consider energy usage in their analysis.

The research question addressed in this study is to identify and assess building construction, transformation, and deconstruction approaches that maximize a building's residual value at the end of life. This study examines the techniques currently in use in the banking industry. It also considers techniques proposed in the literature and assesses their usefulness as a metric of circularity. Finally, a new method for assessing circularity based on the design for manufacture and assembly (DfMA) technique is proposed. This technique can aid the designer or lending institution when considering the potential for reuse or refurbishment of materials within a building.

2 Background

2.1 Circular Economy

The business world and pop culture frequently refer to the circular economy. A difficulty associated with making progress with respect to adoption of circular economy principles is the different interpretations of what constitutes circularity [3]. At its core, circularity leads to sustainable growth and prosperity for all mankind [4]. Unfortunately, existing metrics with respect to achieving circularity indicate mixed progress. Within Europe, the wealthier countries in the North and West are making progress towards a circular economy, but most of the countries in other parts of Europe are not [5].

While there is no commonly agreed upon succinct definition of what constitutes a circular economy in the context of construction, there are two agreed upon principles [6]. One of the principles identified by Korhonen et al. is the recycling, reusing, or refurbishing of materials. This is in contrast to the predominant linear model for a building lifecycle of extract – produce – use – dump. A second major principle is the reduction of energy use and carbon footprint [7]. Financial institutions have relied on the second principle, energy use, with little regard for the first principle, recyclability .

2.2 Construction Industry

With respect to adopting circular economy principles and practices, the construction industry is not performing as well. A recent EU report noted that the construction industry is responsible for one third of the waste generated in Europe [2]. That same study noted that while 80% of the companies involved in construction rated adopting circular economy principles as high or very high priority, only 29% of the companies were actively engaged in any form of reuse or recycling of building materials [2].

The construction industry is fragmented and dominated by small and mid-size enterprises (SMEs) [8]. These companies normally do not have an R&D department that can develop new construction techniques, nor do they have large service organizations that can refurbish reclaimed construction materials. They must rely on other organizations in the value chain to do that work. In addition, due to the fragmentation, the company doing the deconstruction and refurbishment is normally not the company doing the original design or construction. Therefore, since a different part of the value chain is involved, there is no inherent business value for the design and construction firm to embed deconstruction features in their work. They do not realize any economic benefit such as increased sales or lower costs from performing that work.

2.3 Construction Financing

The European Union Taxonomy for Sustainable Growth includes the regulation EU 2019/2088, Sustainability-Related Disclosures in the Financial Services Sector [9]. This standard requires financial institutions operating within the boundaries of the European Union to post data on their website concerning the environmental and ESG risks within their portfolio of loans. There is no set format stipulated in the regulation for how the information is to be presented, so each bank has its own approach.

A review of the websites of the top 50 European banks in 2024 found that all had at least one page on their website that discussed sustainability within their loan portfolio [10]. There was a wide variation in the presentation of information including the breadth and depth of that information on the websites. However, the overarching emphasis was on carbon reduction. Every bank is doing something, but because of the lack of consistency it is impossible to compare the different banks to determine which are providing the most support for circular construction.

3 Methodology and Analysis

This study is conducted in two phases. The first phase is a qualitative analysis with two parallel paths. One path is the review of the current practices at financial institutions. This involves a review of the website of the top 50 financial institutions providing lending services to the real estate market in Europe [10]. It also includes interviews with loan managers at three of the banks. The second path is an assessment of tools discussed in the literature that can be used to analyze building residual value at the end of the building lifecycle. The second phase of this research project is the analysis of a new technique that can be used for assessing a portion of the residual value of a building.

3.1 Financial Institution Analysis

Within the European Union, financial institutions are required to maintain a page on their website that reports on the ESG status of their loan practices [9]. There is no fixed requirement for format or content. The top 50 European financial institutions were identified on a website maintained by Standard & Poor's, Global [10]. The webpage that addressed the ESG status for lending at each institution was reviewed. The common theme across all websites was that carbon reduction was an element in their decision process when placing loans. Other factors such as diversity and community development were also mentioned on some websites. No bank featured a discussion concerning the evaluation of reuse or recycling when making loan decisions.

The review and analysis of websites was augmented with interviews with current loan managers from two of the top 15 European banks and an interview with one of the leading European consultants on finance and the circular economy. All three said that loans for building projects with a good energy efficiency score received favorable treatment. One bank indicated that the amount of the loan they would approve was impacted by the energy score and the other bank indicated that the percentage interest rate could be impacted by the energy score. A common practice among banks is to rely on third party certification for the energy usage assessment. In addition to energy usage, one bank relied on the anticipated revenue when estimating the loan valuation for a new commercial building. That bank anticipated that revenue would be increasing during the life of the loan. The other bank was more likely to rely on the construction costs and market value of the building when determining loan amount. The bank strategist confirmed that these were the two commonly used methods when establishing a property's value at the end of life for a building. In either case, the building residual value may vary, although it generally would be higher than at the time of construction.

All three of the interviewees agreed that banks do not currently take the final building value into consideration when making a loan. One bank assumes the building will increase in value, so they are not worried that the building value will ever drop below the value of the remaining principal on the loan, The other bank took the view that when the loan was repaid they no longer had any interest in the building so they did not care if it had a residual value. Therefore, neither bank considered any factors for reuse or recycling of the building or building materials. One bank indicated that they would only include the cost of demolition in a construction loan when the organization requesting funding would be doing the deconstruction of a pre-existing building. Even then, it was only considered an expense element for disposal of construction and demolition waste. There was no perceived benefit from reselling, refurbishing, or reusing the material. However, all three interviewees expressed an interest in a metric for reuse as an additional factor that would be used in making loan decisions.

3.2 Construction Material Reuse Metrics

There are no commonly accepted metrics for assessing the reusability of construction materials at the time of initial construction. Even at the time of deconstruction or demolition there are no widely adopted metrics. Bertino et al. highlighted the importance of planning before starting deconstruction in order to minimize waste [1]. This planning entailed both the deconstruction process and the process for restoring or refurbishing recovered materials. In addition, when Salimi and Taherkhani conducted a bibliometric study of lifecycle assessment in building construction, they found a significant cluster in the area of design for disassembly [11]. Techniques in this area would meet the need for improved planning as identified by Bertino et al. [1]. In addition, Guerriero et al. noted a severe lack of circular and regenerative design tools [12]. In many cases, architects and engineers do not know the circularity implication of their design decisions.

However, there are several metrics that have been proposed for use when performing deconstruction or building transformation planning. One approach discussed in numerous studies is to consider the building at the end of its life as a material bank [13]. Although the recovered material can be valued at market prices, a major limitation with this approach is the lack of tools or techniques for evaluating the disassembly process. The cost to extract the materials during deconstruction, building transformation, or demolition is not easily estimated [12]. In addition, the extracted materials must often go through a process of testing and evaluation to determine if they can be safely reintroduced into the construction supply chain. In fact, a study done by Pilipenets et al. found that analyzing the cost of construction waste during deconstruction is still highly variable [14]. Most companies doing deconstruction do not have the capability to restore or refurbish the recovered materials. These must be transported to an organization that specializes in restoring or refurbishing recovered material.

In addition to the concept of a material bank, Hartwell developed a scoring method for determining the reclamation potential of building materials based on the building lifecycle, material characteristics, and how the materials are used [15]. This metric requires an assessment of the building use prior to deconstruction. The methodology creates a reclamation potential score measured as a percentage. It does not provide a monetary value. However, the reclamation potential percentage can be used with the material costs to estimate a value for the recovered material. The limitations of this methodology are that it can only be used at the end of the building's life, and it does not adequately address the difficulty and necessary labor to extract the materials.

4 Alternative Approach for Assessing Building Valuation

4.1 Design for Manufacture and Assembly

The design technique known as Design for Manufacture and Assembly (DfMA) is a well-established design methodology used in many industries [16]. This methodology enables the designer to consider downstream implications of current design decisions. The technique is a scoring methodology that calculates a score reflecting the ease of manufacturing and assembling a product or system [17]. The principles of DfMA began to be codified by companies building weapon systems to support World War II [16]. The technique was refined by Boothroyd and Dewhurst in the 1970s and 1980s [17]. This technique is used in the automotive, aerospace, and consumer products industries and taught as part of the curriculum for many industrial engineering degree programs.

Typically, designers are focused on meeting the needs of the customers or users by optimizing the functional performance and features of the product or system being designed [16]. Once the design is completed, the industrialization process begins to determine how to fabricate and manufacture the components of the design and how to assemble those components into the final product or system. The DfMA technique initiates the industrialization process earlier in the design cycle while the product or system is still being designed [17]. Incorporating factors revealed in the DfMA analysis leads to lower costs, higher quality, and shorter manufacturing cycle time. The scoring method starts with a functional analysis of each component or part to determine if it adds functionality to the system. Unnecessary parts or components add unnecessary costs to manufacture the unneeded component. In addition, assembling the unnecessary components into the product or systems adds additional unnecessary cost and time. Once the necessity for the part is established, the DfMA scoring system modifies the part of component score based on factors that create added time or effort to handle the part or component and factors that address added time or effort to attach the part or component to the others that make up the assembly.

The Boothroyd-Dewhurst DfMA technique provides a score for each part or component in the bill of materials and a composite efficiency ratio for each assembly or system [17]. Designers are encouraged to eliminate unnecessary parts that have no function to reduce the total part count. In addition, the scoring reveals attributes of the parts or components that create hazards or difficulty when handling. When designers become aware of these issues, they can often redesign parts or components to reduce this impact. Additionally, Boothroyd and Dewhurst did extensive research to understand the complexity and difficulty of various methods for assembling the system. A process such as welding is more complex than attaching components with nuts and bolts which is more complex than just snapping parts together.

4.2 DfMA Challenges within the Construction Industry

Theoretically, DfMA can be used as an analysis technique during construction, transformation, or deconstruction of a building. Any time building components are installed or removed, DfMA can provide an analysis of the effort required. However, given its development within industries characterized by high production volumes and standard parts, a legitimate question is whether DfMA can be applied to onsite building construction. Rankohi et al. studied the attempted use of DfMA in both off-site and on-site construction and identified 45 challenges associated with incorporating this approach [18]. Most of those challenges were not unique to the construction industry but are associated with implementing organizational change. Examples of some of those challenges include management of customer expectations and poor coordination among stakeholders. However, four of the challenges were directly related to the use of the DfMA technique within the on-site construction environment.

- Difficulty in identifying appropriate DfMA tools/techniques in each phase.
- Higher design costs than the traditional design methods
- Difficulty in financial management and lack of an efficient payment method
- Lack of awareness of DfMA benefits among owners/developer.

The first of these challenges is related to the nature of on-site construction. DfMA was developed in a manufacturing environment characterized by high-volume standard part production. On-site construction, transformation, and deconstruction are normally characterized as low volume operations, and each building is unique. To use traditional DfMA elements in this environment, the focus needs to shift to process steps, which are more likely to be standardized and are relatively high-volume. When focusing on process steps, the difference between construction and deconstruction is almost nonexistent. One is essentially the other in reverse order.

The second challenge is associated with higher design costs than the traditional design methods. This will likely be true since a DfMA analysis is an additional design analysis that is not normally included in construction projects. Unfortunately, the project savings identified in the analysis will not lower the design costs. The savings will occur in lower procurement costs because of the elimination of procurement of unnecessary components and lower labor costs during onsite construction. This is where the fragmentation in the construction industry can create a barrier to adoption of DfMA [8]. The organization doing the design work is seldom the one doing procurement or onsite construction. Therefore, the design organization does not receive the benefit from the cost savings identified through the use of DfMA. Unless the customer specifically requests a DfMA analysis, the additional design effort increases the design costs and may jeopardize the design organization's ability to win the design contract.

The third challenge is also linked to the high level of fragmentation in the construction industry [8]. Each contractor has a different and unique scope of work for which they are paid. A DfMA analysis may cause multiple contractors to "lose" money. For instance, a fixed price design contract "loses" money when it conducts extra analysis beyond the minimum needed to meet contract requirements. A time and materials construction contract "loses" money when the work is done faster than expected since there is less time billed to the customer. The major beneficiary of a design that has incorporated the results of a DfMA analysis is the end customer. However, if the customer or their representatives do not insist on a DfMA analysis, it is unlikely that it will be done.

The fourth challenge is the lack of awareness of DfMA and the impact it could have on a construction project. Since DfMA is not commonly used in the construction industry, the lack of awareness is to be expected. The primary benefit from DfMA is a lower cost to the customer due to the labor savings that comes from simplified assembly. Since many construction project customers are not construction professionals, they may be unaware of how estimating is done. Construction labor costs are normally estimated based on the size of the building and material costs. There is no provision in the estimating tools for factoring in DfMA effects. It will require a customer advocate, such as the project financing arm, to advise the customer to ask for this type of analysis.

4.3 Design for Assembly and Disassembly

DfMA is only concerned with the initial assembly of the product or system, not the disassembly. However, in the construction lifecycle, all three phases of construction, transformation, and deconstruction should be considered. The DfMA technique is focused on assembling the product or system in the manufacturing plant. This could be considered similar to construction. In the Boothroyd-Dewhurst model there was no element of the technique that was concerned with the end-of-life disassembly, reuse, or disposal of the product or system [17]. However, the recent focus on circularity in the construction industry brings the need for disassembly to the forefront [11]. The DfMA analysis can be reversed to represent transformation and deconstruction.

Traditionally, the creation of construction and demolition waste (CDW) created by transformation and deconstruction of buildings was considered to be of no value [19]. This perspective is changing. The circular economy principles promote recycling, reuse, refurbishment, and remanufacturing construction material over disposal of those materials in landfills [2]. However, the economic viability of recovering usable construction materials from CDW requires a controlled disassembly process to prevent damage to the materials. In addition, that process needs to be fast and inexpensive for the effort to be profitable [1]. Currently, the assessment of the ease of disassembly does not normally occur until the building transformation or deconstruction is about to start, which is many years after the building was designed. Therefore, the analysis of the potential for reuse of building materials is performed based on current market value of the materials [13]. There is no consideration made at the time of initial building design and construction for how the building will be disassembled many years later.

Depending upon the assembly processes typically used in construction, there is significant potential for damage to the materials during disassembly. Often that damage can be avoided if different choices are made during design and construction.

The need for design for disassembly is now becoming recognized. Salimi et al. noted that design for disassembly was one of the major themes in recent journal articles that addressed circularity within the construction industry [11]. However, in a literature review of 18 peer-reviewed journal articles that directly discussed design for disassembly during the period from 2020 to 2024, only one provided any design guidance that could be used by building designers [20]. Zhan et al. noted that the number one barrier to implementing design for disassembly was the lack of tools or techniques [21]. In addition, Zhan et al. found the most efficient strategy for encouraging implementation was to offer financial incentives for conducting design for disassembly analysis [21].

Although there are recommendations for applying design for disassembly techniques, the transformation and deconstruction phases form most buildings are not points of interest to the developers or builders during the construction process. However, applying the DfMA techniques to lower costs and reduce on-site construction time often is a concern. By combining the DfMA technique with design for disassembly, a composite technique, Design for Assembly and Disassembly (DfAD) could create significant synergy. The assembly portion of DfAD identifies the opportunity for immediate savings and the disassembly portion of DfAD calculates a circularity score that could be used by financial institutions when making loan decisions. This technique then addressed the construction phase, transformation phase, and eventual deconstruction phase of a building. The organizations in the value chain best positioned to advocate for the use of this technique are the banks and lending institutions.

5 Design for Assembly and Disassembly Example

5.1 Technique Elements

The proposed DfAD methodology is based on the proven Boothroyd-Dewhurst DfMA methodology [17]. This analytical technique is built on the structure of the bill of material developed during the design process. Every item on the bill of material is first evaluated for its contribution to functionality. The DfMA technique considered three elements of functionality [17]. Does the component need to move as part of its normal operation? Does the component need to have unique material properties because of its function? Does the component need to be removed because it was an item that required regular service? If the answer to all three was "No" then the item was a candidate for elimination. The item could be eliminated with no impact on functionality, or it could be combined with another item in the design. The combination item would likely be more complex, but there would be fewer items in the assembly which normally equates to less assembly time and better quality since there are fewer possible mistakes of forgetting an item, damaging an item, or incorrectly connecting an item.

The DfAD approach has added two additional questions beyond the three used by DfMA/ These are relevant to building design and the construction industry. The first question is, "Does the component create a new planar surface that defines a building or room size and shape?" The reason for this additional question is because a fundamental purpose of construction is to define a volumetric space where people live, work, or play. This space is defined by the walls, floor, and ceiling of the room or building. The second additional question is, "Does the component need to be removed to provide access to other components for service or disassembly/" The previous question dealt with servicing the component itself. This question is related to safety and disassembly. Some components function to hold things in place and prevent unintended access or disassembly. Once installed, the answer to the other four questions would be "No," However, at certain time in the lifecycle of the building, the component needs to be removed. Therefore, it needs to be a unique part. A "No" answer to all five questions indicates the designer should consider a different design that eliminates this component or combines it with another. If the answer to any question is "Yes" then the part must remain an independent part. The total number of parts that had one or more "Yes" answers is the theoretical minimum number of parts (TMNP). When the analysis is complete, a building component efficiency ratio (BCE) can be calculated.

$$PCE = \left(\frac{TMNP}{\text{Total number of parts}}\right) \text{ x } 100\%$$

Once all items on the bill of material have been assessed for elimination and the design updated, the assembly efficiency aspect of the design can be calculated. DfMA evaluated an extensive set of part characteristics that would assign scores to an item based on the item size, shape, and any special handling concerns. Once the handling scores are established, the assembly process is reviewed, and scores are assigned for factors associated with positioning and securing the component in the product or system. The DfAD scores are based on values found in the published DfMA database [17]. The scores represent the amount of time or effort associated with handling, positioning, and attaching the component. Components with very high scores are those that require extra effort and add complexity to onsite assembly. The scores for each component in the assembly or system are summed and that value is used to create a building assembly efficiency ratio (BAE) for the system or assembly.

$$BAE = \frac{3\ x\ TMNP}{Total\ of\ part\ assembly\ scores}\ x\ 100\%$$

At the same time as the construction components are being scored for assembly, they can be scored for disassembly. The scoring for handling of the components is usually the same for both analyses. Although it is possible that during the deconstruction process some of the special handling factors might change, such as the presence of sharp edges requiring safety protection. The disassembly processes are essentially the reverse of the assembly processes, however some disassembly processes such as breaking bonds or removing welds, are scored at a higher level than the original process because of the disassembly effort. In addition, a disposal score is added to each component based on its likelihood for reuse, recycle, refurbish, remanufacture, or disposal. The actual decisions for component disposition will not be made until building transformation or deconstruction. At this time in the design process when the components and systems are being scored, the designers use the most likely disposition of the product. Again, the scores for all components in the assembly are summed and a building disassembly efficiency ratio (BDE) is calculated.

$$BDE = \frac{3\ x\ TMNP}{Total\ of\ part\ disassembly\ scores}\ x\ 100\%$$

5.2 Technique Analysis

The DfAD technique was tested by analyzing two structures that were identical in outside size and shape but built with different construction methods. The structures were part of an Icebox Challenge that is used to demonstrate the value of designing buildings to meet passive house standards [22]. The analysis was only on the basic structure and the outside cladding since this was the only portions of the buildings that were similar. Both structures were approximately 3 meters by 3 meters square. Both had a sloped roof with the short side 2 meters high and the tall side nearly 3 meters high. As part of the Icebox Challenge, both structures were erected in a plaza in Oslo, Norway where they stood for one month exposed to normal weather conditions.

One ice box structure was built using traditional construction techniques. The basic structure was connected with steel plates and screws at the joints. The outside cladding panels were nailed onto the basic structure. When it was time for disassembly, the cladding had to be removed with a crowbar, some of the cladding was damaged. The basic structure of beams was unscrewed.

The second structure was built with snap together components. The basic structure snapped together at the joints with custom joint elements. The cladding was clipped onto the basic structure using a commercially available clip system that was certified for outdoor structures. When it was time for disassembly, the first piece of cladding was removed with a special tool that released the cladding panel clips. After that, the clips to the other panels could be reached. The snap joints for the basic beam structure could be released with a pair of pliers. No components were damaged.

The results of the analysis of the two structures are found in Table 1. The snap-together structure was much more efficient in all categories. Both structures had the same theoretical minimum number of components since the two structures were essentially identical in size and shape. With respect to BCE, the traditional construction was very inefficient due to the high number of screws and nails that provided no unique functional value. The snap-together construction BAE was approximately six times more efficient than traditional construction, which implies that the onsite construction time would be six times faster than the standard construction. The BDE was significantly different. This was due in part to the much faster disassembly time and the fact that the snap-together construction components were undamaged and immediately ready for reuse. However, some of the traditional cladding components were damaged and could not be reused without first being refurbished.

DfAD Metric	Traditional Construction	Snap Together Construction
Building Component Efficiency (BCE)	1.82%	17.39%
Building Assembly Efficiency (BAE)	1.50%	9.07%
Building Disassembly Efficiency (BDE)	0.30%	5.36%

Table 1. DfAD Metrics

6 Conclusion

The construction industry has been slow to adopt circular economy principles. An exception is the banking industry that provides loans for construction and real estate. All major European banks are complying with the EU Taxonomy to provide information about the circularity attributes of their loan portfolio. All the banks are highlighting their initiatives with respect to carbon usage, but none are emphasizing the reuse, recycling, and refurbishment assessment within their loan portfolio. Based on interviews with loan managers, this is not a metric being used, in part because there is no commonly accepted metric for building construction reuse. Several metrics have been proposed but all are calculated at the end-of-life of the building, not at the time of construction and therefore not at the time when loans are being originated.

The DfMA methodology was explored as a technique that is done during the design phase of a project but is analyzing the likely process efficiency when a product or system is in production. This technique was adapted to the construction industry and expanded to include the disassembly analysis of a building. The new methodology is referred to as Design for Assembly and Disassembly. It provides metrics that can be used to evaluate both material and labor costs of construction and to evaluate the labor costs of deconstruction. This metric can be used to estimate a portion of the residual value of a building and assess the degree to which components can be reused.

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