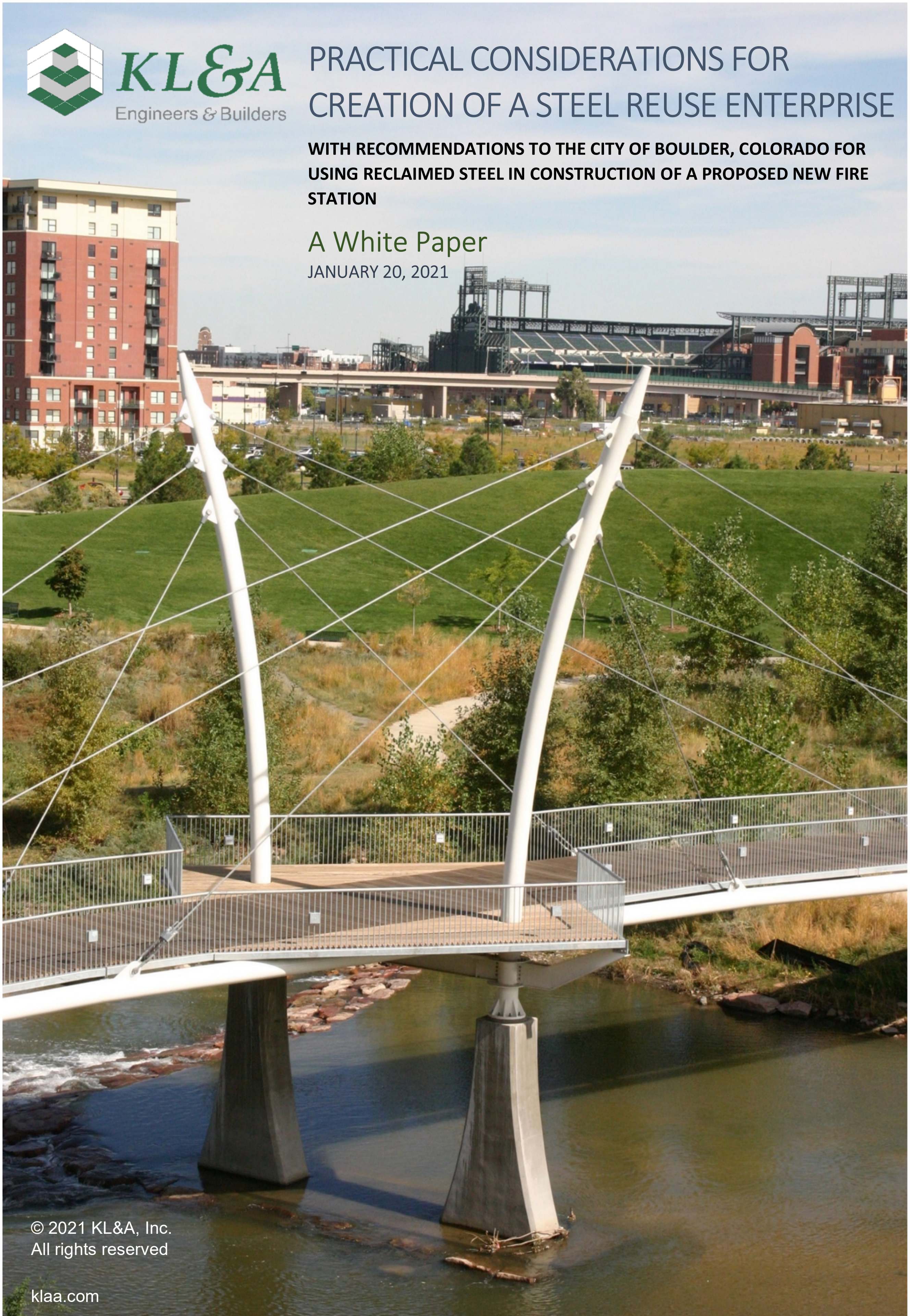
KL&A
Engineers & Builders

PRACTICAL CONSIDERATIONS FOR CREATION OF A STEEL REUSE ENTERPRISE

WITH RECOMMENDATIONS TO THE CITY OF BOULDER, COLORADO FOR USING RECLAIMED STEEL IN CONSTRUCTION OF A PROPOSED NEW FIRE STATION

A White Paper

JANUARY 20, 2021



klaa.com

Table of Contents

Executive Summary

In the United States, steel obtained from the demolition of steel framed buildings is viewed, for the most part, as scrap. Combined with other scrap steel extracted from worn-out automobiles, household appliances and other manufactured products, it becomes the input material for the recycling industry. Readers of this paper are encouraged to adopt a different perspective; rather than an input material for recycling, steel reclaimed from obsolete structures should be viewed as a potential building material.

From this perspective, the reader is asked to consider the potential benefits of direct steel reuse as well as a number of practical issues to be taken into account when thinking about adoption of a steel reuse program.

The environmental advantages of steel reuse are discussed herein under the heading of "Motivation". Greenhouse gas emissions from current practices, as well as potential reductions resulting from increased steel reuse are quantified.

Available sources of steel for reuse, including the nuances of evaluating a potential source, are discussed and guidelines are presented for initial selection of source materials under the heading of "Sources".

The section entitled "Assessment and Documentation" deals with fundamental requirements for rigorous evaluation and documentation of source material. The necessary components of an assessment and documentation program are outlined and a formalized activity entitled "Reclaimed Steel Source Assessment" (RSSA) is proposed as a response to these needs.

Deconstruction with the intent of preserving steel for reuse requires the use of practices and procedures beyond those usually employed in building demolition. Additionally, preservation of the identity of source material from its location in an existing building to a storage facility and eventually to its use in a new structure is a requirement. Recommended procedures for these activities are given in the section entitled "Deconstruction, Reclamation and Storage".

The section entitled "Application" discusses potential uses for reused steel, citing example projects from the practice of the paper's sponsoring organization, KL&A, Inc. Of particular interest to engineers, architects, steel fabricators and steel detailers are the perceived impacts of steel reuse on their workflow identified in this section.

Finally, under the heading of "Creating a Steel Reuse Enterprise", the paper envisions a future in which the reuse of steel has become widespread activity. Perceived obstacles to expanded reuse are outlined and potential solutions are proposed. It is hoped that readers will be inspired to help create such a future.

Introduction

In 2020 the Structural Engineers Institute (SEI) of the American Society of Civil Engineers (ASCE) issued a challenge to the global structural engineering community to reduce embodied carbon of structural systems to zero by 2050. Our firm, KL&A, Inc. is responding to that challenge by trying to meet the goal by 2040.

Embodied carbon in structural systems represents the amount of CO_2 and other greenhouse gases emitted by the production, construction and end of life of the materials used in the foundations and superstructure of a building. At the present time, structural engineers have a fairly narrow range of materials we use, the primary materials being concrete, masonry, steel and wood. This white paper focuses on one strategy for reducing the embodied carbon content of structural steel which generally has about 85% of its embodied carbon from the process required to create the material in high temperature furnaces.[1] The reduction pathway envisioned in this paper is that of reusing steel from existing structures that are destined for demolition, thereby avoiding the need for the high temperature process required to recycle the steel.

While the steel industry currently employs highly developed processes for collecting scrap steel and converting it into recycled steel products using the electric arc furnace (EAF), no widely employed processes exist for direct reuse of salvaged steel. The primary purpose of this paper is to discuss some of the perceived issues to be addressed in the direct reuse of steel, and to propose some processes and protocols to be considered in expanding reuse of steel. It is KL&A's hope these processes and protocols will help facilitate increased experimentation in the reclamation and direct reuse of steel. With the experience gained through such experimentation, and with refinement and further development of process and protocol, direct reuse of salvaged steel has the potential to evolve as a widespread activity with standard practices, developed infrastructure, and a commercial marketplace, in short, a new **enterprise** in alignment with a developing circular economy.[2]

Concurrent with the writing of this paper, KL&A is in the early stages of developing the structural design for a new fire station for the City of Boulder, Colorado. The City has expressed a desire to incorporate reclaimed structural steel from a planned deconstruction of an existing hospital site into the construction of the new fire station. Additionally, the City is

---

[1] It is worth noting that Nucor Corporation has recently brought online a new wind-powered steel mill in Sedalia, Missouri. Power for the plant will be supplied under an agreement between Nucor and Kansas-city based Evergy, Inc. The expanded use of renewable sources for steel production could dramatically alter the embodied carbon calculation, although development of the required energy infrastructure may be impeded by huge capital costs.

[2] The term "circular economy" describes an economic system which minimizes waste and maximizes reuse of existing material resources. The European Commission has adopted the "EU Circular Economy Action Plan" as key component of the European Green Deal, an initiative aimed at reducing carbon emissions while creating sustained economic growth.

interested in exploring the potential for stockpiling and using some of the reclaimed steel in future city projects. Appendix A to this document is a summary of our recommendations to Boulder for implementation of these proposals.

Motivation

All evidence points to the increasing risks that our species face due to climate change. Just in the last year the United States has experienced historic droughts, wildfires, hurricanes, and other severe weather events. How will we answer our next generation when asked "what did you do?"

The building construction industry plays a dominant part in the production of greenhouse gases (GHG) that are emitted to cool, heat and operate our buildings. In addition, GHG are emitted in the production, installation and maintenance of the construction materials that are required to create these buildings, and these emissions are known as embodied carbon. When all sectors that create greenhouse gases are looked at, the building construction sector represents about 38% of the total. 38%!!; almost double the greenhouse gases emitted by the transportation sector.

What part does embodied carbon play in this 38% of all GHG emissions? Of the 38%, operating emissions represent about 72% and embodied carbon about 28%. And, when looked at over a 60-year life span of a typical building, including periodic remodelling of furnishings and equipment, the amount of embodied carbon can almost double.

Can the reuse of structural steel reduce embodied carbon and become one of the many strategies needed to curb our GHG emissions? The essential fact in reducing embodied carbon in buildings, is that the reuse of materials that have already been created is the best approach - this applies to all buildings (renovations), furnishings (using durable products), and structural materials (longer life cycle and reuse in new buildings). To get a sense of the scale of the future construction of buildings, by 2060 the world will double the current building stock, effectively creating one New York City every 34 days. The enormity of these numbers compounds the importance of finding better materials to use for our buildings, and to find better ways to reuse these materials.

Structural steel has some great sustainability characteristics, including high strength per pound (efficient), durability, resiliency in resisting extreme load conditions, and the recycling of demolished steel and other metal products to create new steel in Electric Arc Furnaces, predominant in the U.S.

How does the reuse of structural steel compare to the benefits already realized by the current recycling practices that are prevalent in the U.S. marketplace?

Currently, about 88% of all steel structures ever built are still in use, which speaks to the long-term value of structural steel. When steel buildings reach their end of life, the most common course of action is to demolish the building, extract the structural steel and send it to be recycled. In a comparative Life Cycle Assessment[3] conducted to determine the emission of

[3] Life Cycle Assessment (LCA) is an analytical tool for quantifying the environmental impact of a product, system or activity over its useful lifecycle.

GHG and costs of recycling versus reuse, it was determined that reuse resulted in 755kg of CO_2 equivalent/tonne of steel less than recycling.[i] At the end of a steel structure's life, recycling results in the emission of GHG during demolition, separation of steel from the demolition debris, transportation to the recycling facility, removal of fireproofing, shredding into smaller pieces melting and reforming. Reusing steel results in the emission of GHG during deconstruction, transportation to a storage facility, sorting and stacking, transportation to a fabrication shop, and removal of fireproofing.

In the cost comparison portion of the referenced article, the reuse of steel tended to be more expensive than recycling, however the uncertainty analysis showed that under many conditions the reuse of steel would be less costly than recycling. It is clear that, due to the current low frequency of steel reuse, the actual costs are not well understood. The article also reports that the two things that impact the cost of reusing structural most are the costs of deconstruction and the price of purchasing reused steel.

Sources

Example sources of steel available for reuse are:

- Existing steel-framed building structures scheduled for retirement,
- Unused and "drop[4]" steel from manufacturing and fabrication operations,
- Stockpiled fabricated steel originally intended for use in a structure, but unused,
- Stockpiled fabricated steel from deconstructed buildings and other structures,
- Stockpiled fabricated or unfabricated steel used as falsework or other temporary uses, and
- Reclaimed pipe from abandoned pipelines.

Several factors should be considered when assessing the suitability of a potential source. Among the most important of these is the date when the material was first produced. As a general principle, the older the material, the less desirable it will be. The quality of steel from older sources will usually be more difficult to assess and will be generally lower than steel from newer sources. Structural steel was first used in building structures in 1870 and rapidly replaced the use of cast iron as a structural material. In response to the use of this new material, the American Society for Testing and Materials (ASTM) was founded in 1898 and in 1900 published the first industry standards defining the minimum requirements for steel used in structures. Those standards were designated ASTM A7 for bridges and ASTM A9 for buildings. These two standards were consolidated in 1939 into one standard, ASTM A7, for both buildings and bridges which became the prominent standard until superseded by ASTM A36 in the early 1960's.[ii] The reuse of steel from sources dated earlier than about 1940 for structural purposes should be considered with a great deal of caution. Because the mechanical properties and weldability of these older materials are known to vary considerably, they should be thoroughly tested before reuse in a structure. Likewise, steels produced between 1940 and early 1960's should be tested, at least on a lot basis, to determine weldability, as the ASTM A7 standard in effect at the time, while it specified minimum mechanical properties, established no limit on carbon content, a major element negatively affecting weld quality.[iii]

Newer materials, especially unused excess stock, drops, and fabricated but not erected steel will be the easiest to assess and reuse as well as higher in quality. Steel that has already been stockpiled, providing its source has been documented, we will be least costly to reclaim and reuse than steel in a standing structure which will require deconstruction and assessment.

Among the sources available from standing structures, those that will be simplest to deconstruct will be preferable to those requiring more expense to reclaim. A particular challenge to deconstruction of steel buildings is the prevalence of composite beam construction in buildings built during the past 25 years. In composite construction, steel

[4] The fabrication industry uses the term "drop" to describe the unused material resulting from cutting a piece of steel of a required size from a larger piece of stock.

beams and the concrete floor slabs they support are made to function together by welding numerous steel studs the top of the steel beam. These connections of steel to concrete in composite construction necessitate a more surgical approach to deconstruction, resulting in higher labor input and resultant cost.[5] In addition, removal of the studs from the beams required to prepare them for reuse will result in higher reclamation cost.

Reclaimed steel beams from a composite floor showing studs attached to the top flanges and remnants of the concrete floor slab. Separation of the steel slab from the beam without damaging the beam requires more than the usual amount of care during deconstruction operations, resulting in higher than usual costs.

Other factors bearing on the cost of deconstructing an existing building are the extent of collateral material which must be removed in order to extract the steel framing. Heavy masonry cladding, extensive concrete framing, and HVAC equipment and ducting are examples of such materials.

Coatings to the steel are another consideration. Spray applied fireproofing on steel members will need to be removed before the material can be visually inspected and before it is refabricated. Likewise, paint and other coatings will require removal. Galvanized coatings have a high likelihood of being damaged during re-fabricaton operations and will need to be removed by grinding in any area where welding will be used.

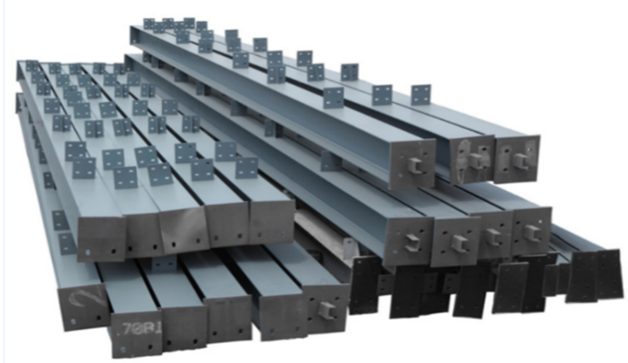
Structures such as vehicle and railroad bridges, crane runways and equipment supports may have been subjected to many cycles of heavy loading or extreme impacts. The strength and serviceable lifetime of steel members in such structures has likey been reduced by metal fatigue, making these members unacceptable for reuse. Other causes for disqualification of steel members for reuse are evidence of fire exposure, visible deformation, and corrosion sufficient to cause a discernable reduction of cross-sectional area.

Availability of reliable documentation is yet another factor to consider. If mill test reports (MTR's) traceable to individual members within a candidate structure are available, little further assessment of the material will be required. If mill tests are unavailable, fabrication records tying mill sources to particular members or groups of members are useful in determining suitability of the material. Architectural and structural drawings and

[5] Several research projects have been completed or are currently in progress aimed at modifying composite construction details to facilitate future deconstruction. As of the date of this paper, none of the proposed alternate construction methods have been widely adopted.

specifications are also valuable in assessing usability. Shop drawings, which describe each component of a structure, including the material specification from which it was to have been made are particularly useful.

The extent and type of fabrication incorporated into the existing steel can affect the cost of reclamation and re-fabrication. Salvaged structural shapes and pipe having no other materials attached will be the least costly to reclaim and re-fabricate. Secondary parts such connection materials, bearing plates, and stiffeners attached to primary members will likely require removal. If these secondary parts are bolted to the main member, cost will be minimal, but if connected by welding they will be more costly to remove. Assemblies such as built-up beams comprised of two or more steel pieces permanently attached to each other and trusses, comprised of multiple members connected to each other at their endpoints, will present challenges to re-use except in the unlikely event they can be used without disassembly. The presence of induced camber[6] may require straightening of the member before it can be reused. Members which have been intentionally formed by pressure into bent or curved shapes will probably not be useful in a new structure.



Steel members with multiple welded attachments.

In summary, the factors of age, practicality of deconstruction, presence of coatings, service history, availability of documentation, and extent of fabrication should all be accounted for when considering a particular structure for reclamation or when comparing a potential candidate structure to others.

[6] Camber refers to the intentional deformation of a steel beam to produce a vertically curved member having a higher elevation at its center than its two ends. The purpose of camber is to offset the downward deflection of a beam when subjected to downward forces in service. Cambering of floor beams is common in composite construction.

Assessment & Documentation

For purposes of this paper, we will use the term "Reclaimed Steel Source Assessment" and the acronym "RSSA" to describe the process whereby information relating to a particular source of potentially reusable steel is collected, analyzed, organized and catalogued. The result of an RSSA will be a collection of documents describing the findings of the RSSA process. Because future users of the reusable steel will rely on the integrity of the RSSA and considering that the individual performing the RSSA requires technical knowledge of steel construction and will necessarily exercise some degree of judgment in compiling the documentation, we recommended that the RSSA's be performed by, or under the direct supervision of, a registered Professional Engineer.

The scope of an RSSA could range from minimal to extensive, depending on the needs of the entity for whom the RSSA is performed. For example, a building owner may want only a general idea of the potential for reuse of steel in a building. An RSSA for this purpose could consist of collecting existing documents, performing a single visual observation and issuance of a brief summary report. At the other end of the spectrum, an owner wising to incorporate steel from an existing structure into a new building may require more extensive inspection and testing, perhaps to the extent of providing individual inspection and testing reports for each piece of steel. If deconstruction of a building is anticipated, the RSSA should include the development of a project-specific Deconstruction Specification.

The fee for conducting an RSSA will, of course, be dependent on the amount of time required for the effort. We recommend that a detailed scope of work to be accomplished be negotiated between the client and the consultant performing the RSSA and that the detailed scope be included in a consulting agreement between them.

Regardless of the extent of the scope of services involved, the product of any RSSA engagement should include a Summary Report and a copy of the detailed scope of work actually performed.

Step 1 of any RSSA should be collection and review of all available documents pertinent to the identified source. Such documents could include construction drawings, shop drawings, BIM models, mill test reports, shop and field inspection reports, photographs, and the like.

Step 2 of the process should be an initial visual observation of the material in situ, whether in a standing structure or in stockpile. The objectives of the initial observation are:

- To confirm that the materials, as viewed, generally match those described by available documents,
- to document any apparent reconfiguration, demolition or addition to the materials not described by the available documents,
- if no documents are available, to generally describe the character and estimated quantity of materials observed,
- to determine the general condition of the materials, particularly noting any detrimental conditions such as evidence of fire, corrosion, or other visible damage,

- to document the presence of any applied coatings, and
- to determine, in general the presence of visible markings such as fabrication or mill marks.

The initial visual observation should be documented by photographs and a written narrative describing the observations made.

Accomplishment of Steps 1 and 2 and delivery of a Summary Report represent the minimum scope of an RSSA. More fully developed RSSAs could include:

- A Deconstruction Specification, including marking and grouping instructions and requirements for disassembly of connections.
- Material testing requirements,
- Material Certification,
- Preparation of a material tracking plan,
- further visual observation,
- extensive photo documentation,
- inspection by qualified inspectors,
- consultation and/or coordination with deconstruction contractors, general contractors, or design professionals,
- preparation of supplementary reports such as recommendations for deconstruction and reuse, life cycle assessments (LCA's), opinions of probable cost,
- preparation of a specification for reuse of reclaimed steel in a new building,
- development of a building information model (BIM).

Deconstruction, Reclamation & Storage

Demolition, as opposed to deconstruction, is the prevalent method of removing an existing steel framed building from a site in the U.S. The steel recycling industry requires a steady input of scrap material which is supplied, in large part, from demolition of buildings. Recovery of scrap through demolition requires no special care to preserve the quality of the material and no documentation of its source.

Deconstruction, on the other hand, requires the exercise of care and special procedures to prevent damage to the removed materials and the preservation of information concerning its source. Building deconstruction will most likely be performed by contractors whose primary business is demolition. When selecting a contractor for deconstruction, there are several factors to consider.

Does the contractor have:

- Demonstrable experience in the deconstruction of steel framed buildings,
- Supervisory personnel and workers with skill and training in deconstruction methods,
- the proper tools and equip needed for deconstruction work,
- experience in marking, and documentation,
- an understanding of methods for preserving building stability during deconstruction, and
- a safety program and procedures to prevent injury.

Once a contractor is selected, and preferably before agreeing to final contract terms, we recommend convening a pre-deconstruction meeting to establish a common understanding of the deconstruction methods to be used and the expectation of all parties. Some topics for resolution in a pre-deconstruction meeting are:

- Requirements for applying identifying marks to the steel,
- methods for disassembly of connections,
- procedures for preventing damage to the steel,
- requirements for segregation of materials into groups for shipment and storage,
- methods for separation of steel from other materials, especially concrete,
- whether any on-site reclamation work such as removal of fireproofing is required, and the extent of such work,
- control of dust and noise,
- the contractor's safety program and emergency procedures
- identification and remediation of any hazardous materials,

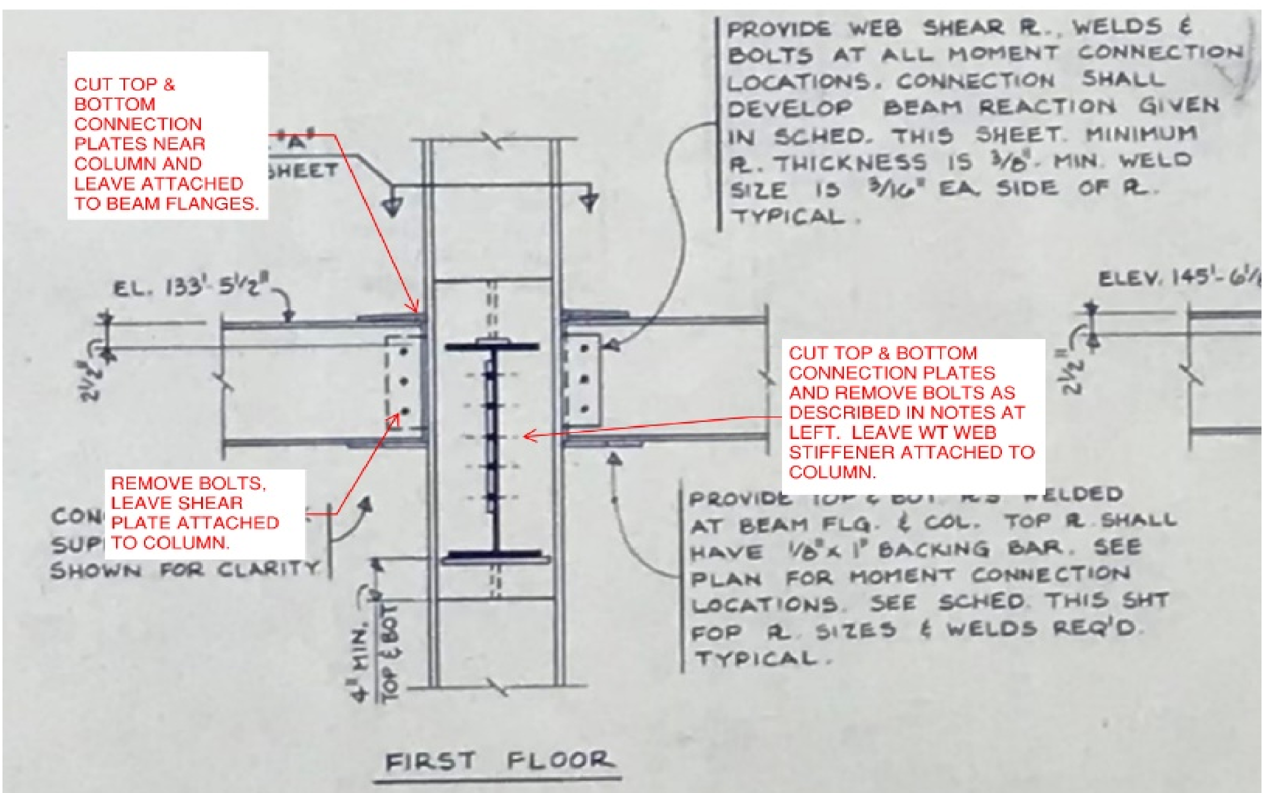
Segregation of salvaged steel members into groups for storage is highly desirable for two reasons: (1) location and retrieval of a particular member for future use will be easier if it is located among like members, and (2) the properties of all the pieces in a group of like material could be ascertained by inference by testing a small sampling of the group, perhaps a single piece.

Salvaged members should be individually marked to preserve their identity and original location within the salvaged structure.   Marking methods should be durable enough to withstand several years of exposure to weather. The use of marking methods used by the steel fabrication industry such as paint sticks, bar-coded labels and stamped metal tags are all possibilities.

The composition of the groups to be segregated and the requirements for marking individual members, as well as the strategy for sample testing, should be defined by a pre-determined plan developed as part of the RSSA and followed by the deconstruction contractor.

Partial or total collapse of a building structure is common in demolition operations but unacceptable in deconstruction. To prevent collapse, the deconstruction contractor must adopt a plan to assure stability of the structure at every stage of deconstruction. Such a plan will define the sequence of deconstruction operations and the method of providing temporary bracing, if required.

Acceptable methods for disassembly of steel connections should be determined before deconstruction operations are undertaken and should be established by the RSSA. Removal of bolts will be the most straightforward method of disassembling bolted connections.



Example of a connection detail from the Boulder Community Hospital structural drawings annotated with instructions to the deconstruction contractor.

Welded connections will be cut using cutting torches or demolition saws, the permissible locations for cuts having been established by the RSSA.

Reclamation, for purposes of this paper, are the processes of removing damaged material sections, unwanted connections, and adherent materials from steel members from used steel members. The extent to which reclamation is performed will depend on the eventual reuse of the material and the fabrication processes required to convert the material for that use. The presence of connection materials such as clip angles, shear tabs, base plates, and cap plates will prevent movement of steel members on roller conveyors used by most fabrication shops and should be removed for achieving fabrication efficiency. Member ends which become damaged during deconstruction operations should be removed. Paint and other coatings may need to be removed to permit welding during fabrication or to allow for recoating of the material. Decisions of whether reclamation processes are to be made on site during deconstruction, at an off-site temporary storage location, or at the fabrication shop where the materials are prepared for a new building should be made prior to commencement of deconstruction operations.

Salvaged steel members should be stockpiled, whether at a fabrication shop or an off-site storage yard, on dunnage to prevent contact with the ground, with markings visible and arranged in pre-determined groups according to the plan in the RSSA.

Application

Reclaimed structural steel has been used in the construction of new structures on a relatively small scale in the U.S. Three successful projects involving steel reuse in which our firm KL&A participated, serve as examples of how reclaimed steel can be incorporated into a new structure. Two of these projects involved the use of reclaimed steel pipe as primary structural members. The third involved the reuse of open web joists.

The Sixteenth Street Pedestrian Bridge over the Platte River in Denver, Colorado is a cable-stayed structure which incorporates repurposed partially fabricated and excess stock pipe as masts and deck stringers in the new bridge. The use of this material, which had been acquired and stockpiled by the City, in conjunction with the lightweight deck construction enabled by the cable-stayed design, saved several hundred thousand dollars in construction costs.

Sixteenth Street Pedestrian Bridge over the Platte River in Denver, Colorado. The reclaimed pipe used for the two masts had been previously rolled into a curved shape in anticipation for use as top chords in a trussed arch. The reclaimed pipe used for the deck stringers was in the form of stock lengths. KL&A was the structural engineer and steel detailer.

The Research Support Facility (RSF) on the campus of the National Renewable Energy Laboratory (NREL) in Golden, Colorado is a 220,000 square foot office building completed in 2010. In response to NREL's challenge to the building design team to find creative ways to reduce the overall environmental impact of the project, repurposed pipe from the oil and gas industry was used to construct primary columns and other elements of the structure. According to a study of the project conducted by Colorado State University, the use of salvaged material saved 69% in CO_2 emissions and 68% in energy consumption as compared to newly manufactured equivalent structural sections.[iv]

Stockpiled reclaimed pipe used for columns in the RSF

Research Support Facility at NREL campus in Golden Colorado during construction showing reclaimed pipe columns. KL&A served as structural engineer, steel detailer and miscellaneous metal supplier for the project.

The Freight building was a major renovation of an old single story industrial building in the River North district of Denver, Colorado. Renovation involved removal of the existing open web joist roof, addition of a second floor and re-use of the open web joist framing for a new roof.

The Freight Building in Denver, Colorado showing the new structural steel floor and old open web joists used for the new roof. KL&A performed the structural engineering.

While most of the opportunities for incorporating used steel will likely be in the form of newly fabricated individual structural steel members made from reclaimed steel members, other uses should be considered for special situations. Entire existing steel trusses could be used without significant modification to support long span roofs or floors provided they have the required capacity and fit within the dimensional constraints of a new structure. A study conducted at the University of Genoa, Italy involving the proposed reuse of roof trusses from an old industrial building for construction of a new railway station concluded that the reuse of the existing trusses would result in savings of 30% in energy consumption and CO_2 reduction.[v] Open web joists, commonly used in commercial roof structures and similar to trusses in construction, could be used as-is subject to similar loading and dimensional constraints. The Freight project cited above is an example of such a reuse. Non-structural and decorative fabrications such as screens, railings, fencing and sculptures present opportunities for using salvaged steel, including undocumented and/or non-certifiable material.

The prospect of increased use of salvaged steel in new structures presents some new considerations for architects and engineers. Structural engineers will need to develop expertise and procedures for evaluating and approving proposed sources of used steel materials. The existence of a professionally prepared Reclaimed Steel Source Assessment, as proposed by this paper, could greatly facilitate this process. A paper entitled *Structural Steel Reuse* published by the UK-based Steel Resource Institute (SCI) is a good source of information related to reusing steel, including testing and design recommendations.[vi] In some instances, engineers may require additional testing and/or inspection before accepting a particular source of reclaimed steel. Established structural analysis and design procedures may require modification to account for differing mechanical properties among new and reclaimed steel used in the same project. Some engineering firms may choose to develop a specification for salvaged steel such as that developed by the firm of Walter P Moore for a University of North Texas project and outlined in an article published in the May 2010 edition of Modern Steel Construction.[vii]

Building codes regulate how our buildings are designed and it is important to consider any provisions in the codes relating to the reuse of steel. To our knowledge, the 2018 edition of the International Building Code (IBC) has one section that can be interpretated to address the use of structural steel that is not marked, or whose source is unknown. Section 2202, "Identification of Steel for Structural Purposes" has this sentence at the end of the section: "Where the steel grade is not readily identifiable from marking and test records, the steel shall be tested to verify conformity to such standards." The standards referred to are AISC 360, "Steel Construction Manual", and the "ordered" grade shall be in accordance with the specified ASTM standard. From Section 2202, it would appear that identification of grade, conformance with the ASTM standards for that grade, and design according to AISC 360, would allow the use of salvaged steel. The other code provisions that may have regulations regarding the reuse of salvaged structural steel are in the International Existing Building Code, which was chapter 34 of the IBC until the creation of the IEBC in the 2012 code cycle.

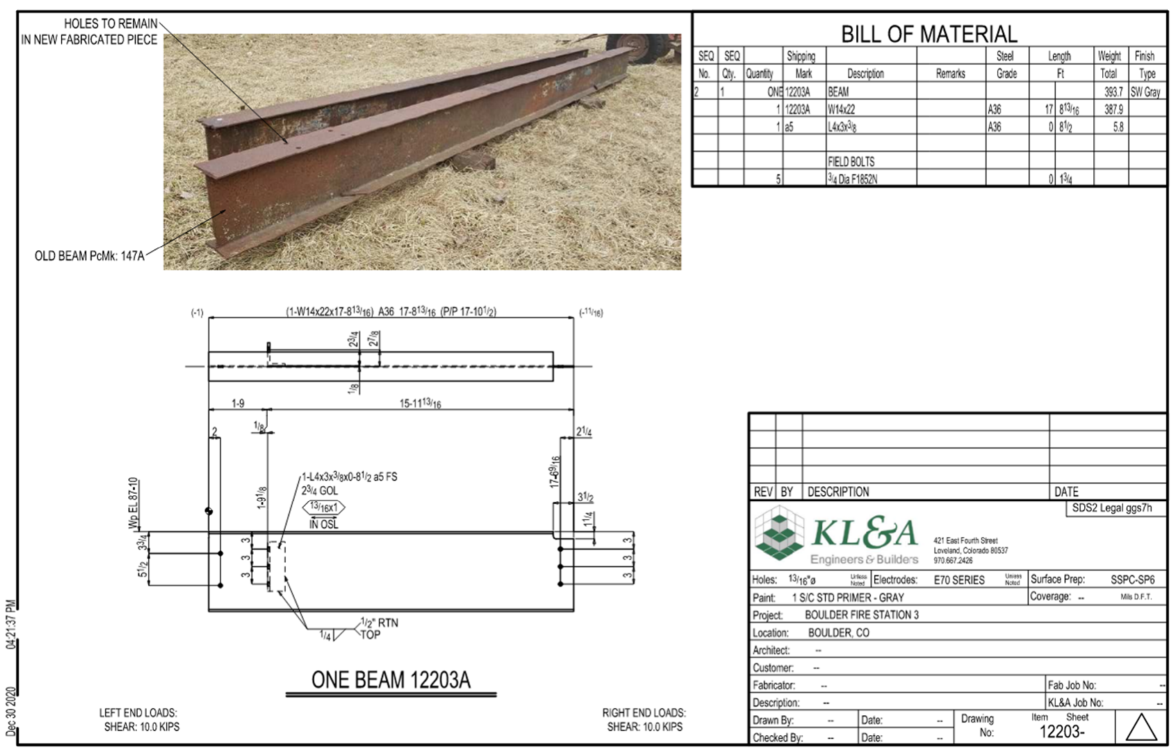
The IEBC defines an existing building as one that was designed in accordance with a previous building code, and as such are exempt from compliance with current building codes. In our review of the IEBC, we could find no provisions or requirements relating to the use of salvaged steel.

It is our opinion that the provisions of the 2018 IBC, section 2202 prevail for the use of salvaged structural steel, specifically that the identification of the grade of steel and conformance to the ASTM standard for that grade, along with the design requirements of AISC 360. This can in certain circumstances, require additional testing of the material to determine compliance with the corresponding ASTM standard. Understanding the existing physical condition of the steel along with its history of use are also important in determining the suitability of reuse for the salvaged materials. In the end, it is the responsibility of the structural engineer to certify in some manner that the salvaged steel is suitable for reuse.

The challenge of using salvaged material may motivate designers to think differently about the design process; instead of first laying out the building plan then selecting the framing system and materials to support that plan, some design assignments may require designers to devise a plan to incorporate salvaged materials already selected.

Depending on the extent of connection materials, presence of bolt holes, presence of coatings or extensive corrosion of salvaged steel for use in a new structure, steel fabricators and steel detailers may be required to perform certain tasks in addition to those usually performed for new steel. As previously discussed, a steel fabricator may be required to complete some reclamation work before beginning actual fabrication operations. Coordination of the deconstruction and reclamation processes with the fabricator responsible for converting the used material into new steel framing is advised.

Steel detailers, who are responsible for creating the detailed fabrication drawings and instructions for the fabricator, will be required to add special instructions for reclamation to the shop drawings. The following illustration shows a potential scheme for adding an annotated photo of a reclaimed beam to the shop drawing for the new beam from which will be fabricated.



Mock-up of a shop drawing for a steel beam fabricated from a used beam illustrating the use of a marked-up photo of the used material to convey instructions to the fabricator.

Creating a Steel Reuse Enterprise

As discussed under the heading of "Motivation" above, there is a compelling environmental reason for pursuing more reuse of structural steel as part of an overall strategy to reduce carbon emissions in building construction. However, notwithstanding this compelling motivation, use of reclaimed steel in new structures has been accomplished with success in only a relatively small number of projects in the U.S. and Europe. Widespread use of reclaimed steel has been hampered by several barriers, some actual, some perceived. An article from the British publication *New Steel Construction* (NSC) published in 2017 and based on interviews and on-line surveys cites the following seven barriers in descending order of their importance:[viii]

1. Availability of reclaimed sections; particularly of the desired size, volume and in the right location
2. Issues relating to the quality, traceability, and certification of reclaimed sections.
3. Additional cost associated with using reclaimed sections.
4. (Lack of) supply chain integration; particularly communication and sharing information through the supply chain and trust (and risk sharing) between companies.
5. Additional time required within construction programmes to allow for using reclaimed steel; in general, additional time incurs addition cost.
6. Reclaiming and reusing structural steel is a relatively uncommon practice and many organisations simply do not have the skills or experience to do it.
7. The perception that reclaimed steel is somehow inferior to new steel sections.

We postulate that most of these barriers can be overcome simply by more widespread use of reclaimed steel resulting from more experience and improved access to knowledge.

Simply finding sources of available reclaimed steel is difficult. A few Individual sources of reclaimed and surplus steel can currently be found through internet searches, some examples of which are:

https://midcitysteel.com/surplus-used-steel/
https://apexpipe.com
https://lombardmetals.com

Attempting to find used steel for use in a particular project by searching through a limited number of individual sites such as these is time consuming and impractical. As an alternative, the creation of a widely recognized online database of available used and surplus steel from a multitude of sources throughout the country, including material documentation of the type generated by the Reclaimed Steel Source Assessment program proposed above, could address the problem of finding suitable materials for a project. Such a database will be necessary component of a national steel reuse enterprise.

The individual and collective skills and knowledge required for the implementation of a steel reuse enterprise will be acquired through experience. Grassroots small-scale reclamation and reuse projects, like that being explored by the city of Boulder Colorado, create public awareness and provide participants with knowledge of how to replicate and expand future reuse projects. These small-scale experiments drive change in the building construction industry.

It is our belief that more organizations, both public and private, will require reduction of embodied carbon in their future building construction programs as a matter of policy. The effect of thousands of organizations implementing such policies will create an industry demand for architects, engineers, developers, and contractors having experience and knowledge in sustainable building design and construction. Steel reclamation and reuse will increase, standards and practices will evolve, needed supply chain connections will be developed, and a commercial marketplace will emerge. A steel use enterprise will thus assume a role in the building industry's response to climate change.

Appendix A – Summary of Recommendations to Boulder.

Background: The City of Boulder owns the property and buildings of the previous Boulder Community Hospital at 1100 Balsam, and has plans for reusing some buildings, removal of most of the hospital building, and new development. Boulder has committed to minimize demolished parts of the building that would enter the waste stream, and there is a current focus on the potential reuse of the structural components of the buildings to be removed. The project team for the new city fire station raised the possibility of reusing some of the structural steel from the buildings being demolished, and the city is embarking on the first phase of this concept focused on a well-defined portion of the hospital buildings. The current plan is to test the concept of deconstruction and reuse of structural steel from one area of the existing hospital building for use in the new fire station, currently in the early phases of design. In this test case, Boulder will be able to track the costs and other assets required for deconstruction and the creation and operation of a steel storage facility.

Process for Reclaimed Steel Source Assessment and Reuse: The first step in this process is the creation of an inventory of structural steel suitable for use. In this test case, drawings of the area of the building targeted for reuse are available, and the creation of a Building Information Model (BIM) would be the first step in producing an inventory of suitable steel. Upon completion of the BIM, the inventory of steel would be developed and would include information needed to define the reusable steel components for future projects. The initial information in the inventory data sheets derived from the model and other sources would include the component's location and use in the existing building, dead and live loads used for design, size and length, additional materials welded to the member for connections or miscellaneous uses, holes installed in the member, and anything else that may be pertinent to its reuse in the fire station or on other projects.

Once this BIM-based inventory is completed, the next step would be to deconstruct the building and place the steel in a storage area, segregated by section type, size and length. The deconstruction would require planning and coordination with the city, a structural engineer, and a contractor who either specializes in the demolition or erection of structural steel buildings. From this initial planning, a deconstruction plan and procedures would be developed and agreed upon, and the building deconstructed, resulting in the salvaged steel placed in the storage area.

After all of the salvaged steel has been placed in the storage area, visual inspections of the steel would be performed to confirm the inventory information and to determine the physical condition of the components. Spray-applied fireproofing will make a thorough inspection more difficult, however limited manual removal of the insulation would enable inventoried steel to be inspected to a level where the steel can be planned for reuse. If there are any remaining questions about material properties of the salvaged steel, additional testing would be performed on representative elements. All findings from the physical inspection would be incorporated into the inventory data sheets.

At this point the steel is basically ready for reuse on future projects by the city or others. The inventory data sheets would be made available to the fire station design team for their use, and the construction documents would incorporate the salvaged steel where appropriate. Upon completion of the construction documents for the fire station, the general contractor would hire a contractor to fabricate and erect the structural steel package. The fabricator would be selected based on a commitment to utilize the salvaged steel as indicated and would reflect this in their proposal. At some point the selected fabricator would pick up the steel from the salvage yard and transport it to their shop for the removal of the spray-applied fire proofing, the structural detailing process, and final fabrication.

It is not feasible to expect that all of the steel from the area selected will be reused in the fire station, and the excess salvaged steel would become a valuable resource that can be used for other city projects or sold to others. The decisions on future storage, maintaining and managing this resource, and tracking the inventory will largely be worked out during this test case.

If the test case works, the next phase recommended is to extend the sources of steel to be salvaged to the remaining buildings on the site. This would require an inventory of steel components available within the remaining buildings on the site. This inventory would consist of a review of existing drawings plus visual inspections to determine shapes and sizes not shown on the existing documents. The documentation of this inventory would be created by a combination of BIM models, data from field inspections and other sources. The remaining steps would be similar to the test case, with lessons learned incorporated into the process.

References

[i] Yeung, J. et al. Understanding the total life cycle cost implications of reusing structural steel. Article in *Environment Systems and Decisions* **March 2017**

[ii] Gustafson, K. Evaluation of Existing Structures. *Modern Steel Construction* **February 2007**

[iii] Miller, D. Sc.D. P.E. Welded Connections – A Primer for Engineers. *Steel Design Guide 21* **2006** American Institute of Steel Construction

[iv] Guggemos, A. Ph.D. Franklin, S. P.E. Greening Steel Construction. *Modern Steel Construction* **May 2011**

[v] Pongiglione, M. Calderini, C. Material savings through structural steel reuse: A case study in Genoa. *Resources, Conservation and Recycling 86* **2014**

[vi] Brown, D. BEng, CEng, MICE, Pientel, R. MEng, MSc, Sansom, M. BEng, PhD, CEnv, MICE, *Structural Steel Reuse, Assessment, Testing and Design Principles*. **2019** SCI Publication P427

[vii] Winters-Downey, E. S.E., LEED AP. Reclaimed Structural Steel and LEED Credit MR-3 – Materials Reuse. *Modern Steel Construction* **May 2010**

[viii] Sanson, M. Structural steel reuse. *NSC magazine*. posted online **April 6, 2017**