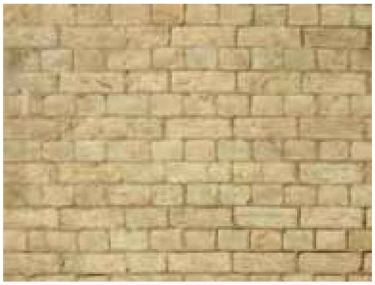
15 Re-using metal components

without melting them

Having looked at diverting production scrap back in to use without melting, can we apply a similar approach to components from products at the end of their first life? For larger components, particularly for steel beams used in construction which are generally not damaged at all in use, we may not need to recycle them by melting: instead, could we reuse them directly?



Cambridge white bricks

Boring red brick

Shipping containers designed for long-term reuse

Property prices in Cambridge are high, and planning restrictions tight, so the town has a community of builders specialising in house extensions. Loft conversions, kitchen extensions and garage alterations abound as we all try to maximise our living spaces on our small plots of land. The great expansion of housing in Cambridge, which between 1800 and 1950, as the town's population grew from ten to ninety thousand, was constructed principally using the Cambridge White brick[1]. However, as we expand our houses today, we have a problem, because the Cambridge White is no longer made, and although we can buy prosaic red wire-cut bricks cheaply from the local Builders' Merchant, we'd rather keep the style of our houses consistent. So there is an active market in reused Cambridge White bricks, and they currently cost around £0.85 per brick, compared to £0.50. Any demolition work is done with care to preserve the value of the bricks, which are mainly undamaged from their first 100 years use and can be deconstructed easily, because 19th century lime mortar is weaker than today's Portland cement.

The story of the Cambridge White has raised all the key issues for us in this chapter: there is demand for old Cambridge Whites, so there's an incentive for builders to deconstruct rather than demolish old buildings, and most bricks are undamaged so ready for reuse after simple cleaning. How does this translate for steel and aluminium?

In the last chapter we looked at diversion of scrap and components that had not yet been used, and in the next one we'll look at extending the life of whole products, which is also a form of reuse. There are also some goods, such as shipping containers and steel sheet piling (see our box story overleaf), which are designed for long-term reuse. In contrast to these approaches, in this chapter, we're looking at the opportunity to reuse components, after they have been used in a product 'in anger.' Our motivation for this is obvious: for both steel and aluminium, recycling

Inventive reuse of steel

"Carhenge" in Nebraska[9]

by melting saves energy compared to making metal from ore, but is still energy intensive; reuse without melting potentially offers a very low-energy supply of components, if the only energy required is for dismantling and re-assembly (in the case of the old Cambridge Whites). Are there opportunities for re-using steel and aluminium, and if so, how extensive are they, and how can we develop them further?

It takes little thought to realise that steel and aluminium are already being reused in various ways. To start with a couple of extremes, the pictures to the side are a reminder of the creative reuse of metal goods in one of the world's poorer countries, and the extravagant "artistic" reuse of metal in the richest one. But neither picture illustrates a future business model, so let's turn to some more commercial examples:

- Car dismantlers and salvage companies break up damaged or old vehicles to re-sell components as low price spare parts. This approach has gained momentum with the use of the internet to reach a larger market, and is particularly strong for heritage vehicles.
- Rail track is regularly reused—firstly by swapping over the left and right rails on a track, as the train wheels wear away only the inner edge of the rail, and later by 'cascading': when rails are no longer suitable for main-line use, they are ultrasonically tested for cracks, cut and welded to length and reused on secondary lines with lower traffic. The box story describes a new strategy for re-using rail even more.

Sheet steel piling

Steel piling is used on construction sites as a temporary structure to hold back soil or water while foundations or retaining walls are erected. Once the permanent structure is strong enough the sheet piles are removed, cleaned, trimmed of any buckled portions and then reused on another site. This process can be repeated 5-6 times per year, after which the main UK manufacturer of steel piling will buy the sheet at a pre-determined rate if in good condition.

Carrwood Park

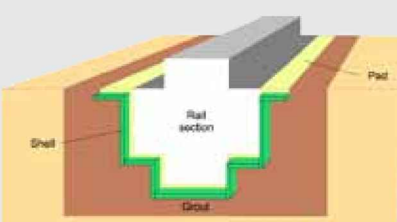
- The British Construction Steelwork Association's new headquarters building at Carrwood Park is one of several examples we've found, where new steel-framed buildings have been constructed from used steel. In fact we think that the opportunity for steel reuse in buildings is so important that the second half of this chapter will focus entirely on construction.

- Famously, around half of the world's retired ships are beached on the shore at Alang in North West India and then manually dismantled. Major components are re-sold, but the steel plate from which the ships are constructed is cut with oxy-acetylene torches into plates that can be lifted off the beach manually, and eventually these are heated, and re-rolled for reuse. The destination of this steel is not very well documented, but we understand that much of it becomes reinforcing bar for construction across India, and in 2008, ship-breaking was contributing up to one eighth of all Indian steel demand[2].

Recovered ship plate ready for re-rolling

- By law, all oil drilling equipment installed into the North Sea must, at end of life, be removed. In 2007 BP's North West Hutton rig was decommissioned, and dismantled by Able UK in Teesside. Able UK chose to reuse the 'topsides' of the rig (the accommodation block) as their own office, and also broke the steel jacket (the legs) into sections that could be re-rolled. Over a quarter of the 20,000 tonne rig was profitably reused.

Re-use of steel and aluminium components is already viable, and exactly as we found with Cambridge White bricks, each of our examples has included (a) dismantling to separate an end-of-life product into components, (b) cleaning and processing of the old component to prepare it for reuse, and then (c) delivery into a willing market. We can look in turn at these three features, to understand the potential to reduce demand for liquid metal production by reusing components.



A novel track design for increased reuse

A common mechanism of failure in rail-track is wear of the railhead. Replacement is often due to the deterioration of only the surface material. Re-usable designs are looking to extend the life of the remaining material. One idea is to redesign the shape of the rail with a double or quadruple headed rail, supported in a continuous bed of concrete instead of sleepers, but mounted so that it can be withdrawn and rotated when worn, to provide a new contact surface. We've looked at the total embodied emissions of this design—accounting for increased concrete and reduced steel use—and if the rotation doubled the life of the rail, the total embodied emissions of the track per year of service would be greatly reduced.

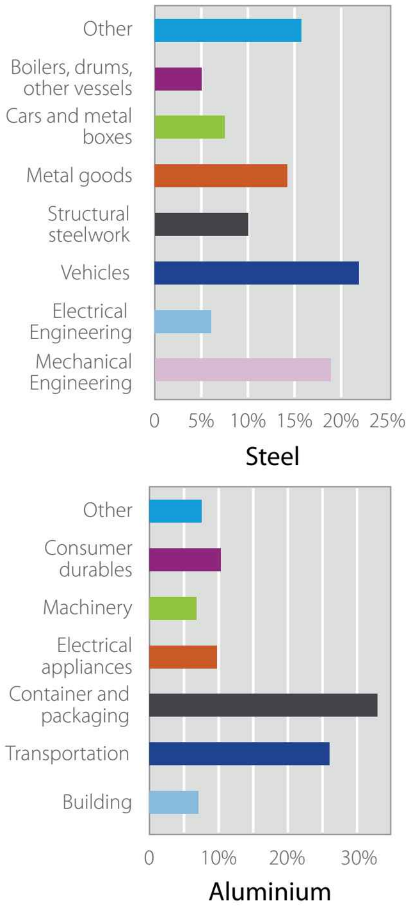


Figure 15.1—**Estimates of scrap availability**

Dismantling end-of-life goods to create a supply of components for reuse

What components could be reused? We could give a great answer to this question if we could station a few students at the nation's metal scrap yards, and ask them to keep a detailed log of everything that came in over a year or so. Remarkably, several students around the world have done exactly this and we salute their commitment! But fortunately we can make a useful estimate in a different way. We looked earlier in the book at the flow of metal into products, and made estimates of the life-span of different product types. So, armed with a history of production in each main sector, we can predict the types of products currently being scrapped and sent for recycling which might instead be reused. Figure 15.1 shows our estimates[3]. The distribution has changed from the product catalogues in chapter 3, because some goods last longer than others.

To reuse components we need to extract them without damage and at low cost. We can extract them either by cutting them out, or by disassembling a product into its parts, so it seems rather obvious that products should now be designed with mechanical joints (such as nuts and bolts) so they can be taken apart later. However, there are several other requirements too, mainly driven by the fact that disassembly is much more expensive than assembly. A key to this is because, unlike assembly where tasks can be standardised to gain economies of scale[4], in disassembly each task is different, so costs more. The UK's wonderful facility for shredding one million fridges per year (we'll come back to it in chapter 16) does have sufficient repeating tasks (if only it didn't…) to standardise the removal of key components prior to shredding. However, building deconstruction must occur on-site, so is always a 'one-off', and vehicle disassemblers must process whatever cars arrive—generally each car is different from the one before. Without standardisation, disassembly is expensive unless products are designed with disassembly in mind. For example, it should be easy to identify parts, and it should be possible to remove any one part without having to remove several others first. Table 15.1 provides a summary of what we've learnt about design that supports cost-effective component extraction for reuse[5].

If we ignore cost, almost all assembled products can be disassembled, and the principles in the table give a basis for designing products now so that in future their components can be more easily reused. However, if we want to start re-using components now, we must cope with what's in current designs.

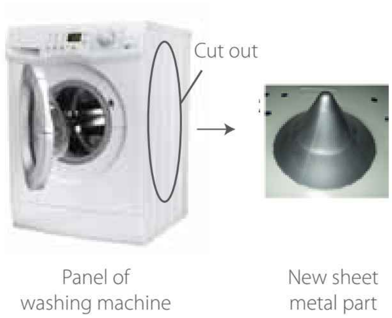


Figure 15.2—**Reforming metal from reclaimed products**

Design feature
Adaptability
Use flexible, open designs that separate strength from function
Standardised part spacing and connections
Use specialised parts only at exterior locations (with use of standard fixtures), ensuring they can be removed
Anticipate possible future needs and design for upgrades
Easy repair and deconstruction
Avoid use of mixed materials, and coatings
Enable easy and quick part replacement or separation of the product or structure
Localise wear surfaces and other sources of failure to small easily replaced components
Develop a deconstruction plan to enhance the value of material content at end-of-life
Traceability
Physically mark alloy grade and quality on components to enable reuse without the need for testing and certification

Table 15.1—**Different options for reuse**

Preparing components for reuse

Having separated a component from its parent product, what should we do to maximise its value? Car dismantlers might do very little, for instance to a working engine part, and simply re-sell the component for use elsewhere. Or they might need to re-spray a body panel, and it's technically possible to clean and re-coat used steel food cans. Every metalworking shop keeps a stock of off-cuts or parts from old jobs, which can be cut into smaller pieces for new uses. We described re-rolling old ship plates earlier, and Professor Erman Tekkaya and colleagues at the University of Dortmund have demonstrated that you can form a used car body part into a new part[6]. In fact most sheet goods retain sufficient ductility that they could be re-formed. Small parts from a previous use or even swarf can be joined into larger parts, as we saw in chapter 13, or as happens in car body repair. So between re-sale and re-melt there's a wide range of options for reuse, which we've summarised in Table 15.2.

In a crisis we would immediately adopt all of these strategies, to conserve the value in existing materials. In our economy at present, manufacturing is so efficient that any reuse requiring additional labour is unlikely to compete with the use of new material, and therefore most of these options are dormant.

However, we've listed the options in order of increasing likely cost, and as we look ahead for options to reduce total demand for liquid metal, we can use this table as a guide. Superficial change—removing a coating, or reapplying one, can be cost effective already—particularly for larger, custom made parts, which are currently sprayed by hand, and 'subtractive reuse' is generally much cheaper than deformative reuse: metal can be cut with generic tools, but can only be formed with special costly tools.

Looking for opportunities for future reuse, we want to find components that can easily be separated from their parent product, and can be reused directly or require only superficial change or simple trimming. To look for candidates, we can now return to the bar charts of scrap availability. Any component that can be reused without change, will be reused already if the cost is attractive, so reuse will increase if the relative difference in price between new and used components expands, or if the cost of labour decreases relative to the cost of the new component. Vehicles and equipment feature prominently in the scrap charts of Figure 15.1 but for different reasons both are difficult targets. Body panels in vehicles are potentially a large source of used sheet steel but by the time cars are scrapped, their design has usually been superseded, so the market for component re-sale without change

No change: the product is resold e.g. second-hand sales of books and clothing, modular construction/deconstruction	
Superficial: only the surface of the product is changed, e.g. refurbished cardboard boxes (label/print/tape removal), thermal cleaning, non-abrasive blasting	
Subtractive: Material is removed from the original product e.g. dye-cutting of used cardboard, rust removal, cutting new shapes from used steel plate	
Deformative: the component is reshaped, e.g. reforming steel columns, re-folding cardboard boxes, re-rolling of steel plate	
Additive: components are joined together e.g. solid bonding of aluminium swarf, welding processes (selective recasting, laser cladding, wire-arc spraying), gluing plastics and paper	
Destructive: conventional recycling	

Table 15.2—**Different options for component reuse organised by increasing cost from top to bottom**

is small. If in future, cars were designed with a common architecture, panel reuse could be valuable, but at present there is little opportunity beyond the existing spare parts market. Re-use of components from equipment is also difficult: equipment is assembled with a wide variety of specialised components, so the market for any particular part is small. With increased standardisation this could change. Packaging is the largest source of post-use aluminium scrap, particularly foil containers and drinks cans. However, regulation on food packaging, the fragility of the packages once emptied, and the logistical difficulty of collecting used packaging strongly inhibits reuse.

So where should we look for the chance to expand reuse? We need an application that uses big pieces of metal that will be useful even if trimmed, that aren't damaged in use or afterwards, and that are sufficiently standardised that they will continue to be useful after first use. And no doubt by now you're thinking that this sounds exactly like the world of steel-framed buildings. We agree, and weren't the first to think of it: step forward David Rose from Suffolk in East Anglia whose family-run business Portal Power takes down, restores, and reuses single story portal-framed buildings. Take a look at the box story on Portal Power to find out more.

Re-use of structural steel looks to us to be a great opportunity that is likely to grow rapidly in the near future and we'll discuss it more shortly. However, before narrowing our focus to this specific application, we need to explore the third aspect of reuse thrown up by our opening story about Cambridge White bricks: where's the market?

Identifying markets

The bricks of Cambridge are reused with a chain of three players: the owners of the old building who decide to sell the bricks; the builders who take down the old building, clean the bricks and often act as stockists; the owners of the new building who specify reused bricks as a requirement. So a market for reused metal will evolve if the three equivalent players all want it to happen:

- The end-of-life chain for scrap metal is mature and efficient: nearly all scrap metal arising in the UK is collected for recycling (by melting). The decision to supply metal for reuse rather than recycling therefore depends on whether a higher price is offered for reuse to pay for the inconvenience of disassembly and careful handling.

- A sufficient network of stockholders exists already, world-wide, to meet the needs of existing manufacturers and constructors for metal. These stockholders already have the required contacts in the market, so are the natural suppliers of reused metal, and will do so if customers are prepared to pay a price for old metal that sufficiently compensates any additional costs related to sourcing, remediating and stocking. The box story shows that for James Dunkerley Steels in Oldham, there is indeed sufficient compensation.

- Clients, designers, contractors or manufacturers would specify reused material over new, either if there was a price incentive or if they found a brand advantage in doing so. However, they will only consider reused metal if the quality of the material, which might need certification, is appropriate to their needs.

Apparently we have defined a clear economic principle about reuse: everyone will do it if the price is right. Clearly that's true, but potentially reuse could also be driven by a changed business model related to modularisation and we'll be exploring that opportunity in chapter 16. There are many opportunities to create modular designs around standard grids, and this approach would greatly increase the value of components at end-of-first-life, by increasing the number of potential second applications. The largest opportunity we can identify for developing reuse appears to be in steel framed buildings, and we'll now explore that specifically.

Portal Power

Portal Power is a business specialising in the design and erection of portal frame buildings. Over 40 % of their 2,000-3,000 tonnes annual throughput is in pre-used portal frame buildings. Portal Power oversees the whole process from deconstruction, through any modification, to final erection in a new location. Deconstruction generally takes 3-6 times longer than demolition, and is not always possible. For example, if column bases have been embedded in concrete, it is too costly to extract them without damage. Changing insulation standards for cladding have also prevented reuse of some cladding sheet in commercial buildings.

After deconstruction, Portal Power stores the steel while waiting for a buyer. When a customer is found, Portal Power can modify the building, adding value to their business. Portal Power provides structural drawings to the new owner, and is investigating shot-blasting and repainting the reclaimed steel to add further value. Portal Power does not currently test the steel, and the majority of the reused buildings they sell are for agricultural use.

Re-use of steel sections in construction

All over the world, large buildings are based on structural frames made either with reinforced concrete or structural steel. In the old days we used to use large blocks of stone, and all we could manage were buildings like the Cathedral of Notre Dame in Paris, Machu Picchu in Peru, Angkor Wat in Cambodia, King's College Chapel in Cambridge and the Taj Mahal in Agra, but our sense of design has moved far beyond that now and instead we make towers and hangars. 8,000 years of development, and global architecture has become a single perfectly harmonised style, so that wherever you are, if you're in a city you're surrounded by towers, and if you're in a shop, a factory, warehouse or airport, you're in a hangar. Towers and hangars, the greatest achievements of design, and we build them all with only two possible material options—reinforced concrete or structural steel.

In France and Italy they still mainly use reinforced concrete, but in the UK, we have steadily shifted towards steel frames: plenty of concrete still to make the floors, and often the central core, but the basic structure is steel. The graph shows an estimated history of construction steel use in the UK, and the second line, the same line, smoothed and shifted forwards by 40 years, is an indicator of the upcoming availability of structural steel in buildings reaching their end of life. We have a growing supply of used structural steel.

James Dunkerley Steels (JDS)

JDS are a steel stockist in Oldham. Up to 20% of their stock is used steel and they sell around 3,000 tonnes of used steel sections per year. They are known nationally as a buyer of used steel and have a long-standing, established business. JDS employ a full-time buyer who visits demolition sites and quotes a price for the steel. The business pays a premium over the scrap price to cover the additional time and effort of deconstruction. To encourage careful dismantling, the steel is inspected on the ground before payment. The steel is then transported from the demolition site to the stockyard in Oldham.

JDS do not test or certify reclaimed steel, but instead 'downgrade' its specification to that of basic mild steel. The turnover of stock is generally 3–4 months, however for steel of standard sizes this may be reduced to just one week. The main customers for reclaimed steel are civil engineering firms, who use the steel for temporary structures and road plate. JDS also sell to local builders and developers, and have a fabrication shop to provide added value to their customers.

Steel framed buildings are bolted together from sections, which form the beams (horizontals) and columns (verticals) of the building frame. Steel sections are not degraded in use, unless the building is damaged by fire, so the supply of steel in the graph could be used to make new buildings. Furthermore, steel sections are standardised, so geometries made 40 years ago are still regularly specified today. And although some sections are limited by strength, which has improved with 40 years of technology improvement in steel making, most are limited by stiffness, which is unchanged. There are no fundamental technical barriers to designing steel buildings now, with 40-year old steel.

A small number of steel-framed buildings have now been built with sections reused from previous buildings, and our colleague Professor Mark Gorgolewski from Ryerson University in Canada has documented several of them. We've worked with him to make an estimate of the emissions benefit of steel reuse, and the box-story overleaf tells the story of those buildings. Overall, we've found that steel reuse requires very little energy, so if we can make a one-for-one substitution, re-using a tonne of steel section gives an emissions benefit equal to making a tonne of an equivalent new section[7]. We have to be careful though—and as the box story on the following page shows, the emissions benefit of reuse in the different buildings is not the same in each case, mainly due to over-specification. This occurs because reuse is not common practice, so in several cases larger cross-sections were used than would be chosen in a new design, and the total mass of steel used was therefore higher. The processes of deconstruction and reclamation required very little energy, and we found no evidence that reuse influenced the energy required to heat or cool a building in use.

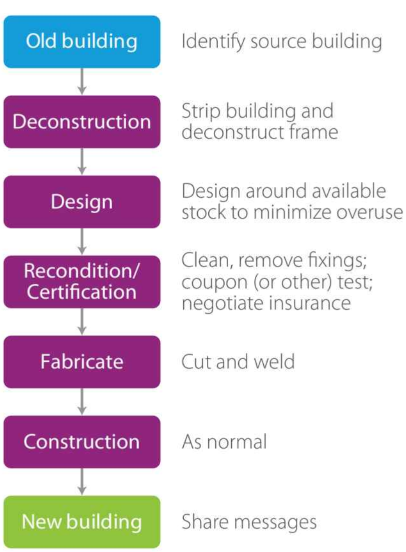


Figure 15.3—**Schematic for designing a building from reused components**

Figure 15.3 shows a simple process flow for building a new building with reused steel. Once the old steel reaches the fabricator (the people who cut the steel to length, and weld end-plates and other fixtures to it ready for assembly) there is no difference between this process and that for a new building, so the key stages of reuse are: sourcing the old steel; deconstruction; reclamation; certification; design. We'll now take a look at each of those stages in turn.

When a property developer buys a site, they first decide whether to refurbish the existing buildings on the site, or replace them. If the decision is to replace, they design a new building, seek planning permission, identify contractors, and wait till they have a client to occupy the new building. During this process the old building stands empty, but when all four elements are satisfied and the programme of work starts, the first contractor onto the site is the demolition agent who is told to clear the site as rapidly as possible. Any delay to demolition causes a delay in the whole

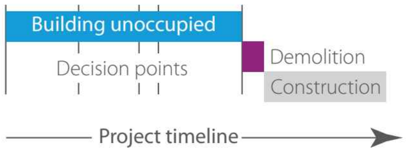


Figure 15.4—**Time-line for building demolition**

programme, and therefore an expensive delay before the tenant starts to pay rent. The quickest way to clear a site is to knock the building down, and current health and safety laws in the UK aim to avoid having people near the building until all the materials are at ground level. Once the building is reduced to rubble, a simple sorting occurs—and in particular old steel is separated and sold as a commodity for recycling. Because they will be melted, it doesn't matter if the steel sections are damaged during demolition. So, if we want to reuse the steel sections from this site, we have to deconstruct the building rather than demolish it.

The time-line in Figure 15.4 re-emphasises the amount of time that the building stands empty before demolition begins—this occurs because nothing happens until all contracts are in place. However, if the developers used separate valuations for a site with an old building and a clear site, they could begin deconstruction earlier without delaying occupancy of the new building. Because deconstruction takes longer than demolition, it costs more, so even if they have time, demolition

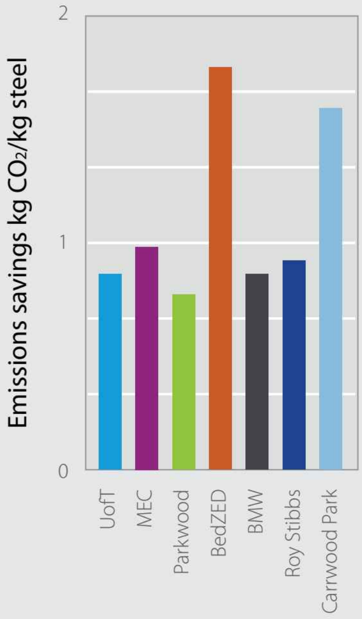


Figure 15.5—**Emissions savings from building reuse**

Re-use of buildings

University of Toronto, Toronto: 16 tonnes of structural steel were recovered from the deconstruction of the nearby Royal Ontario Museum and used in one wing of the student centre.

Mountain Equipment Co-op, Ottawa: About 90% of the original structural steel in the old grocery store was reused in the construction of the Mountain Equipment Co-op store on the same site.

Parkwood Residences, Oshawa: During the adaption of an old office complex into a new residential development, about 90% of the original steel frame was reused.

BedZED, London: 98 tonnes of structural steel were reclaimed from local demolition sites and used for a housing and commercial development.

BMW Sales and Service Centre, Toronto: During the adaptation of an old factory into a BMW Sales and Service Centre, about 80% of the original steel frame was reused.

Roy Stibbs Elementary School, Coquitlam: Following a fire, the Roy Stibbs Elementary School was rebuilt incorporating 466 steel joists recovered from a deconstructed school to speed up construction.

Carrwood Park, Yorkshire: An office-park development reused 60 tonnes of structural steel from existing structures on site and from a private stockpile.

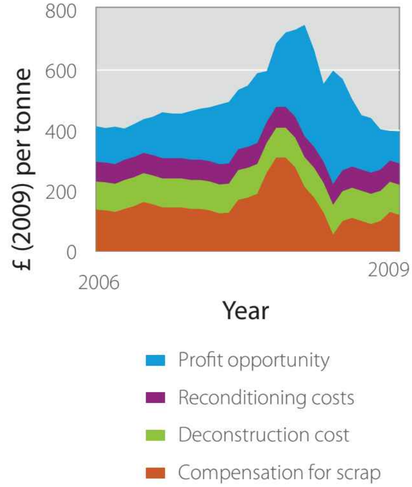


Figure 15.6—**Profit opportunity from steel reuse**

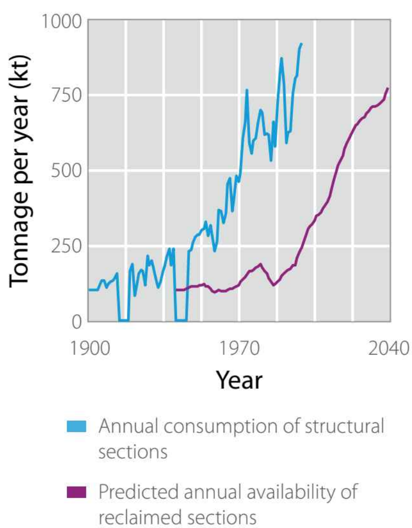


Figure 15.7—**Forecast availability of scrap structural sections in the UK**

agents will only do it if they're paid more. Is that likely? Figure 15.6 shows the history of the price for new steel sections in the UK (top line) and for scrap steel sections sent to recycling (bottom line) between 2006 and 2009. The gap between these is the potential profit opportunity motivating deconstruction rather than demolition. From talking to demolition contractors, we've estimated that the cost of deconstruction is an additional £100 per tonne of steel, compared with demolition, and we've added £70 per tonne for cleaning up the used sections ready for resale. The blue area therefore shows the profit opportunity if reused steel can be sold as a substitute for new steel. The graph suggests that there is enough money available to cover certification costs (to be discussed below) and to offer some incentive to purchasers to choose reused steel over new steel. Despite this opportunity, which is sufficient to motivate James Dunkerley Steels as described in the earlier box, the UK's market for reused sections hasn't yet flowered. We think it very likely that it will: Figure 15.7 suggests that supply will increase rapidly.

Many other business models are possible in sourcing reused steel sections. Table 15.3 shows four ways that clients have already found steel for reuse, three of which do not involve a stockholder. In fact there is a further option which we're now trying to develop into a demonstrator: large retail chains who own their own buildings currently expect the buildings to last for around 20 years, after which the needs of local shoppers or the actions of competitors will create a commercial incentive to redevelop the store. Currently each store is built to order, and demolished destructively at the end of its life. Instead, the retail chains could retain ownership of the building components, and reconfigure them either on the same site or elsewhere to maintain the value of the materials and allow faster construction.

Steel framed buildings are bolted together—fabricators weld plates with holes onto each steel beam or column with sufficient precision that the building is delivered as a kit of parts and rapidly bolted together on site. If we need to demolish buildings rapidly and without people on site, as at present, un-bolting is currently not possible, and instead the weapon shown in the photo is used to smash the facades off the building, and cut the steel sections into pieces. Operating one of these things must be a testosterone fuelled thrill, albeit a depressing one, but they are, of course, extremely effective: we've recently watched one of these monsters eat up a four story office block on the road to our local train station in just two days. If we want to use the steel again, we need a different strategy, and with a change to health and safety laws, we could allow people back onto the site, applying the same safety rules as when constructing new buildings, and either un-bolting or cutting the joints. Alternatively we could look for new approaches to joining steel

A delicate tool for smashing the façades off buildings

that facilitate remote deconstruction: see the box story to the right for a survey of current innovations in the area while the other specifically looks at the problem of separating reinforced concrete floors from the steel frame of a structure.

Steel sections extracted undamaged from old buildings require some reclamation, after which they are visually identical to new sections. However, there is one important difference: new sections are supplied with a certificate that guarantees their properties, and allows for the transfer of responsibility for building failure from the contractor back to the steel supplier. How can this transfer be achieved for reused steel?

New steel is certified based on an audit of the steel mill where it was made. The quality of the whole process from liquid steel to final product is regularly tested with statistical sampling, and each section is certified to have properties at a specified level. The steel companies are highly motivated to get this process right, as they would be legally liable if a building failed because the steel was below specification. We need an equivalent quality guarantee for reused steel

Table 15.3—**Factors affecting the decision to specify reuse in construction**

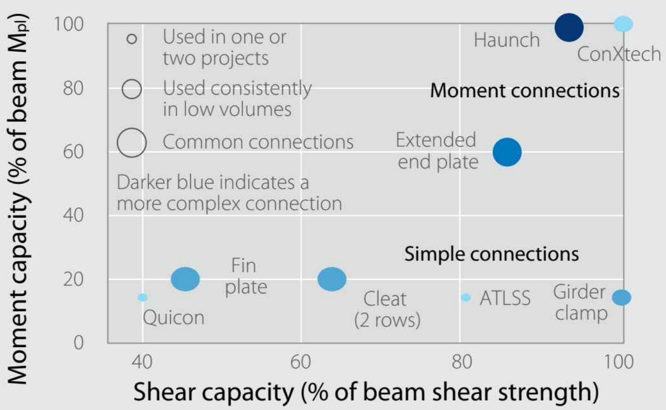
Existing reuse models	Information and certification	Design	Timing and project management
	Reuse of steel in construction		
In-situ reuse: an obsolete building is bought and either adapted, or deconstructed so that components can be reused.	Reduced need for testing: possible access to engineering drawings, current loads known.	Adaptive design based on known materials purchased up front. Possibility to reuse entire building systems.	Single client manages deconstruction, design and construction. Timing naturally aligned.
Relocation: a steel structure is dismantled and re-erected elsewhere, e.g. Portal Power.	Reduced need for testing: same configuration, same loads.	Adaptive design based on steel structure purchased up front.	Buyer is tied to seller's project schedule, possibility of delay.
Direct exchange: steel sections or modules are sold for reuse without an intermediary.	Testing and certification required unless beams are downgraded or buyers trust sellers.	Material pre-ordered or design drawn up with a flexible specification in order to increase likelihood of finding suitable stock.	Buyer is tied to seller's project schedule, possibility of delay.
Stockholder: sections, steel frames or modules are bought, remediated and stocked until a demand presents itself.	Testing and certification required unless beams are downgraded. May only accept standard products.	Material pre-ordered or design drawn up with a flexible specification in order to increase likelihood of finding suitable stock.	Delays can be avoided as stock is supplemented with new material if necessary in order to guarantee supply (this affects reuse content).
	Reuse of manufacturing scrap		
Stockholder: offal from the pressing process is bought, cut to regular sizes and sold for reuse.	Material properties known. No additional testing. Sold for non-critical parts.	Unaffected as irregular offal is cut into standard sizes.	Delays can be avoided as stock is supplemented with new material if necessary in order to guarantee supply (this affects reuse content).

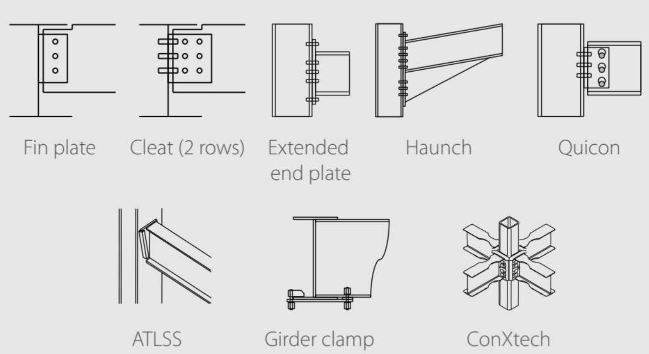
sections. In future, it may be possible to do this simply by providing information, although guaranteeing that paper records are kept safe and can be found would be complicated. Alternatively, a permanent marking on each section could specify its performance. For either of these approaches to work, the insurance industry must learn to trust that the properties of the section are unchanged during first use. At present, they don't accept this, so the required assurance must be provided by testing each reused section. This involves cutting a test sample from each beam, and stretching it in a testing machine to measure its strength. This process requires labour, so is expensive and is an important barrier to reuse. However, as the box story shows, there are other cheaper ways to provide an equivalent test, and part of our ongoing work will be to develop an affordable standard for testing reused steel which is acceptable to the insurance industry.

So, armed with undamaged, clean, certified reused steel sections, designers can now proceed with the new building—but not quite. New steel sections are made

Reversible joints

Joints that lock mechanically and with fewer bolts may allow quicker and safer deconstruction. The chart below presents a range of common and novel structural connections. The joints are grouped into two families: simple connections which resist shear forces (as commonly used in low-rise buildings) and moment connections which also resist bending (as used in portal frame construction). Novel joints such as Quicon, ATLSS, and ConXtech simplify demounting of the beams. Quicon offers simple removal, and ATLSS and ConXtech provide stability with male/female interlocking secured with bolts. Specifying these more novel joints may allow greater reuse in the future.





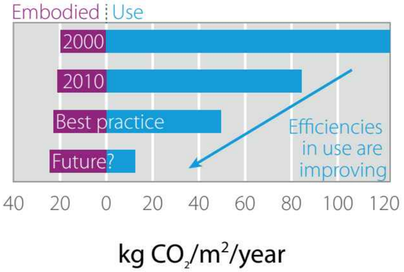
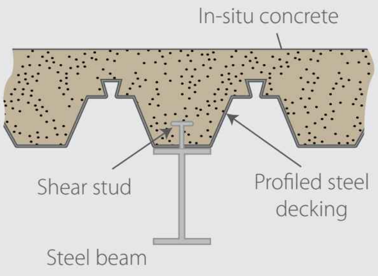


Figure 15.8—**The balance between energy in use and embodied energy in buildings is changing**

continuously, so designers using new material can specify any length, and the range of cross-sections available today is greater than in the past. Design with reused sections may require some modification to the overall design to make best use of available materials. For some clients this could be an advantage: promoting the use of reused steel as a symbolic statement was an important part of the motivation of the case studies examined by Mark Gorgolewski. However, in general, it seems likely that a mix of reused and new steel will give the right combination of design freedom and reduced embodied energy or emissions.

Overall we've seen that re-using steel in construction looks to be a big opportunity in our quest for future material efficiency: reused steel can be used as a direct substitute for new steel, re-certification could be developed, and the supply of steel sections for reuse will grow. We anticipate that the motivation to pursue reuse in construction will grow also. Figure 15.8 gives an estimate of the balance between annual energy use in a retail building, and the embodied energy in the building divided by its anticipated life-span. Improvements in insulation, sealing, and heating and ventilation are driving a rapid improvement in annual energy use, while a tendency towards shorter life-span buildings is driving up the annualised embodied energy. Building operators are already aware of this trend, so looking ahead for opportunities to reduce embodied energy and material reuse offers the biggest impact. At present, the certification standards used to demonstrate energy efficiency in buildings (BREEAM in the UK, see the box story at the end of the chapter, and LEED in the US) are insensitive to embodied energy in the building—but both standards are under review, and proper reflection of embodied energy in these standards will increase the motivation for reuse.

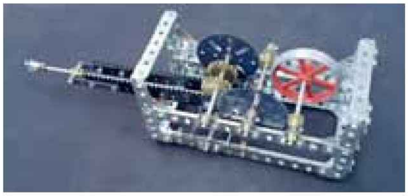


Composite floor removal

Multi-storey non-residential buildings account for approximately 45% of the steel used in UK buildings. The most popular floor design in these buildings since the early 1990's has been the composite steel and concrete deck, combining the tensile strength of the relatively expensive steel at the bottom and the compressive strength of relatively cheap concrete at the top. However it is difficult to deconstruct such floor systems because of the difficulty of ensuring the safety of the deconstructing team and because of the cost of slow unbolting in contrast with fast cutting or shearing of joints. Novel joints might allow quicker separation of the floor modules from their supports, and of the concrete from its coupled steel work, for instance by cutting out segments. A major demolition contractor told us that cutting out would currently take at least 3 or 4 times longer than conventional demolition.

Outlook

This chapter started with reused Cambridge White bricks, and has ended with a focus on the reuse of steel sections in construction, because it looks like such a big opportunity. To promote it we need some lead users, perhaps retailers seeking brand advantage, or the government through its procurement policies, to stimulate demand. The supply of reused steel will follow demand, and could be increased with changes to demolition practice, either driven by changes to regulation, or new approaches to reduce the costs of deconstruction in comparison with demolition. We're currently working hard to stimulate some demonstrators of reuse in the UK.



A Meccano inerter

We've left to the end what's probably the most obvious and well-known example of metal reuse: the famous Meccano kit. Invented by Frank Hornby in 1901 the first Meccano kit used reversible joints (nuts and bolts) with regular spacing between bolt holes, to ensure that components can mate. Since then the number of parts has increased a little, but the number of designs is limitless. Does reuse limit design creativity?

One of the most exciting inventions we've seen in the past 10 years is the inerter invented and patented by Professor Malcolm Smith. The inerter is a new member of the family of basic mechanical components, which includes springs, masses and dampers and allows new designs for car suspensions[8]. It's a great invention, and the photo shows Professor Smith's first model inerter, made of course, in Meccano. Design constraints in reuse? Not that we can find!

Rapid cheap testing of used steel

The Vickers hardness test was invented in 1924 to estimate the hardness and yield stress of a material. A cone indenter is pressed into the surface of the material, with the Vickers hardness defined as the applied force divided by the area of the indented shape. Empirical studies have estimated the yield stress as a third of this hardness value. Portable hardness testing can be much cheaper and quicker than the coupon tests currently used to recertify reclaimed steel. However, the error between hardness testing results and actual yield stress is often greater than 20 %, an unacceptable level of error for insurance companies. Professor Tekkaya at the University of Dortmund has shown that we can reduce this error by considering the changing behaviour of the material as it deforms around the indenter. For a given batch of reclaimed beams, a combination of portable hardness testing, and a small number of coupon tests could allow a satisfactory degree of confidence in the properties of the material.

BREEAM and embodied energy

Voluntary eco-standards such as BREEAM give accreditation for the sustainability features of buildings. Buildings are scored across a number of sustainability criteria. The resulting credits are then combined to produce a single overall score on a scale of Pass, Good, Very Good, Excellent and Outstanding.

The materials category of BREEAM includes an assessment of the embodied life cycle impact of buildings but this is not based on publicly available data, and no minimum targets are set. And while embodied carbon in the structure typically constitutes over 20% of a building's lifetime impact, it is surprising that only approximately 5% of total credits are allocated to reducing its footprint; instead the emphasis is very much on use phase savings. By contrast the Australian Green Star rating system was revised in February 2010 to drive best practice in steel production and fabrication and to encourage dematerialisation of steel structures. Performance criteria for Green Star include minimum strength for rebar and structural sections and offsite optimised fabrication of rebar.

Notes

1. Two of our colleagues in the department of Earth Sciences provide a marvellous introduction to the building materials in Cambridge with their "walking tour around the historic city centre" online (Woodcock and Norman, n.d.)

2. Larger ship plate sections are hot-rolled to a thinner gauge to get rid of imperfections. Smaller sections are cut into ribbons, heated and fed into dies to roll into rebar. The re-rolled plate is sold for use in low-grade construction. There is no certification, and quality is assured only by the re-rolling mill's reputation. Re-rolled plate commands approximately 60% of the certified product price. Professor Asolekar of the Indian Institute of Technology in Bombay, has documented the environmental implications of this practice in two papers: Asolekar et al. (2006) and Tilwanker et al. (2008).

Dismantling end-of-life goods to create a supply of components for reuse

3. Empirical scrap data at the level required for this analysis is difficult to obtain, as waste regulations do not require data collection at a product level. Dynamic material flow analysis (MFA) using data on historic production and product lifetime distributions are used to model the outflow of goods from use by Davis et al (2007) to determine steel scrap flows in the UK, and these results are in good agreement with global discard of steel values produced by Hatayama et al. (2010). A breakdown of aluminium old scrap from Europe, the USA, China and Japan has been produced by Hatayama et al. (2009), again using a dynamic MFA model; these four regions account for about 80% of global aluminium consumption.

4. Although the most authoritative book on the Toyota Production System is that by Taichi Ohno (1988), who invented it, there's a very nice article by Dr Steve Spear of MIT (Spear and Bowen, 1999) that gives a definitive introduction for most of us who are unfamiliar with Japanese culture, so miss the nuances of Ohno's book.

5. Design for reuse principles are abstracted from recommendations and case studies by Addis and Schouten (2004) and Morgan and Stevenson (2005) on design for deconstruction, Kay and Essex (2009) on reuse in construction, and WRAP (2010) on a design team guide for civil engineering.

Preparing components for reuse

6. The remanufacturing of sheet metal scrap is investigated by Tekkaya et al (2008). Hydroforming, where high-pressure hydraulic fluid is used to press sheet metal against a die, is used to flatten contoured sheet metal parts, such as car bonnets. Incremental forming is used on already flat sheet metal parts, such as washing machine panels. Similar ideas on incremental forming of non-uniform sheet panels are investigated by Takano et al (2008).

Reuse of steel sections in construction

7. This is a little subtle—in the UK we actually don't make steel sections from recycled material, although they do in the US, but given that the steel in an old section would be recycled, on average, re-using it will reduce the amount of metal being recycled by one tonne, at the same time as reducing demand for liquid metal by one tonne, so the emissions saving from reuse is equivalent to the emissions of secondary production.

Outlook

8. The inerter looks like an ordinary shock absorber, where one end can be attached to the car body and the other to the wheel set. As the car moves over uneven ground, a rack and pinion or similar coupling causes the rotation of a flywheel inside the device. When combined with a spring and damper, the result is that the inerter reduces the vibration of the car body, allowing the car to have better road holding. Our colleagues in the control-engineering group have documented the advantages of this type of suspension in Smith et al (2004).

Images

9. Author: Plumbago at en.wikipedia (http://en.wikipedia.org) used under Creative Commons Attribution 2.5 Generic Licence (http://creativecommons.org/license/by/2.5/deed.en)