Understanding and overcoming the barriers to structural steel reuse, a UK perspective

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Abstract: To meet greenhouse gas emission targets, at global, national and sector level, reduction opportunities should be explored in both the embodied and operational carbon of the built environment. One underexploited option to reduce embodied carbon is the reuse of structural steel. However, in the UK, work by Sansom and Avery (2014) suggests a picture of declining levels of reuse. This paper explores why this is the case by identifying the practical barriers to structural steel reuse through a series of semi-structured interviews with UK construction industry members. Whilst there were many identified barriers, five practical barriers were prioritised as being most significant: cost, availability/storage, no client demand, traceability and supply chain gaps/lack of integration. These contrast with those most commonly identified in global literature: cost, supply chain gaps/integration, risk, jointing technique, composite construction and time for deconstruction; with only two overlaps: cost and supply chain gaps/integration. Many of the barriers from literature have a technical focus (reducing salvage yield rather than completely preventing reuse) differing from the largely systemic barriers that the interviews prioritised. These systemic barriers will need to be dealt with first to increase reuse rates. This will require a coordinated approach across the UK construction supply chain. Building on interview insights, this paper proposes four mechanisms to overcome these systemic barriers: (1) the creation of a database of suppliers/reused section availability, (2) a demonstration of client demand (3) technical guidance and education for the construction industry and (4) government leadership. Together these mechanisms would improve reuse rates in the UK, reduce the embodied emissions of the built environment and play a crucial role in meeting greenhouse gas emissions reduction targets.

Keywords: Steel reuse, embodied carbon, barriers, circular economy, construction; sustainability

1 Introduction

Substantial changes are required across the construction sector, a significant user of energy and energy intensive materials, if the UK is to meet its greenhouse gas (GHG) emissions reduction target of 80% below 1990 levels by 2050 (Climate Change Act 2008). This is recognised by the sector, whose Construction 2025 aims include a 50% GHG reduction, relative to 1990 levels, in the built environment by 2025 (HM Government, 2013). There is no restriction on when in the life cycle this reduction could occur, although the focus has traditionally been on buildings in-use. However, embodied emissions (those produced from the extraction, processing, manufacturing, transport of materials and construction of the built environment) are also significant, with Giesekam et al. (2014) estimating these at 63 $MtCO_2e$ in 2007 for the UK. This amounts to 9.5% of the UK's 2007 reported domestically produced GHG emissions (Webb et al, 2014); or 5.78% of the UK's reported consumption-based GHG emissions (DEFRA, 2015). Giesekam at al. (2014) also show that, on average, almost half of the embodied built environment emissions occur outside UK borders so will not count towards the UK's 2050 target. There has however been some recognition of the importance of embodied (or capital) carbon reduction. The Green Construction Board's (2013) Low Carbon Route-Map for the Built Environment recommends a 21% reduction in embodied carbon,

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relative to 2010 emissions by 2022, increasing to a cumulative 39% reduction on 2010 levels by 2050 to meet the UK's target. A benefit of targeting embodied emissions is the immediacy of the GHG reduction. Conversely, there is a time lag with in-use emissions reductions. Given the urgency of the climate change challenge, reducing embodied emissions should be an appealing strategy.

Material efficiency (which entails using less material, for longer, while delivering the same function) is a promising option for reducing embodied carbon in the built environment, as suggested by Allwood et al. (2012). The biggest emission reduction opportunities will likely be those focusing on energy intensive, bulk materials; such as steel and cement in the built environment. Globally, in 2008, 56% of steel and almost 100% of cement were used in the built environment, generating 3.2 $GTCO_2$ (Allwood et al., 2012).

Material reuse is one promising strategy for improving the material efficiency of the built environment. This entails reusing material across multiple construction projects over time, with minimal re-processing. Steel in particular lends itself to this approach, as a quick initial review can be conducted to identify deflections, distortions and corrosion and ascertain the potential suitability of reuse before demolition. However, steel reuse is not common practice in the UK, as shown by Sansom & Avery (2014); suggesting there are few drivers for reuse or that there are barriers along the supply chain preventing reuse. This paper offers an exploration into the barriers to structural steel reuse for different actors along the UK construction supply chain.

2 Defining steel reuse

Reuse is defined as the subsequent use of an object after its first life. The object may be repurposed, but its original form will be retained with only minor alterations. As a consequence, the re-occurring embodied carbon is minimal. For steel, the key distinction is that it is not re-melted. It differs from recycling, which is the most common practice at end of life in the UK (Sansom & Avery, 2014) and has a much larger impact on GHG emissions. Table 1, developed by the authors, characterises different types of reuse, distinguishing between in-situ reuse (on the same site) and relocated reuse (moved to another site), for whole buildings, component systems and individual elements. This framework is useful for categorising reuse case studies and for identifying common and differing barriers and drivers. In practice, the type of reuse selected the will depend on technical feasibility, environmental impacts and financial costs.

	In-Situ Reuse	**Relocated Reuse**
Building Reuse	Reuse of a significant portion of a building, e.g. entire structural frame, façade or envelope, in-situ	Deconstruction, and reassembly on a new site of a building frame/envelope
Component system Reuse	Reuse of a small part of a building in-situ, e.g. foundations	Reuse of system of components, e.g. steel truss, on a new site
Element Reuse	Deconstruction and reuse of elements in a new configuration	Reuse of individual elements, e.g steel section(s), on different sites

Table 1: Characterising Variants of Reuse

The decision to reuse steel may be made early in a project if the building is to be reused on-site, or decided at a later stage, during tendering for steelwork, if relocated element reuse. The design team, denoted by the shaded box in Figure 1, is therefore critical in determining the reuse type. Figure 1, shows the different possible procurement routes for obtaining reused steel. There are three possible options: sourcing directly from a demolition contractor (a departure from standard practice, which relies on an awareness of who might have reused steel available), sourcing from a traditional steel stockist or, with the emergence of a new stakeholder, procuring steel from a specialised reused steel stockist.

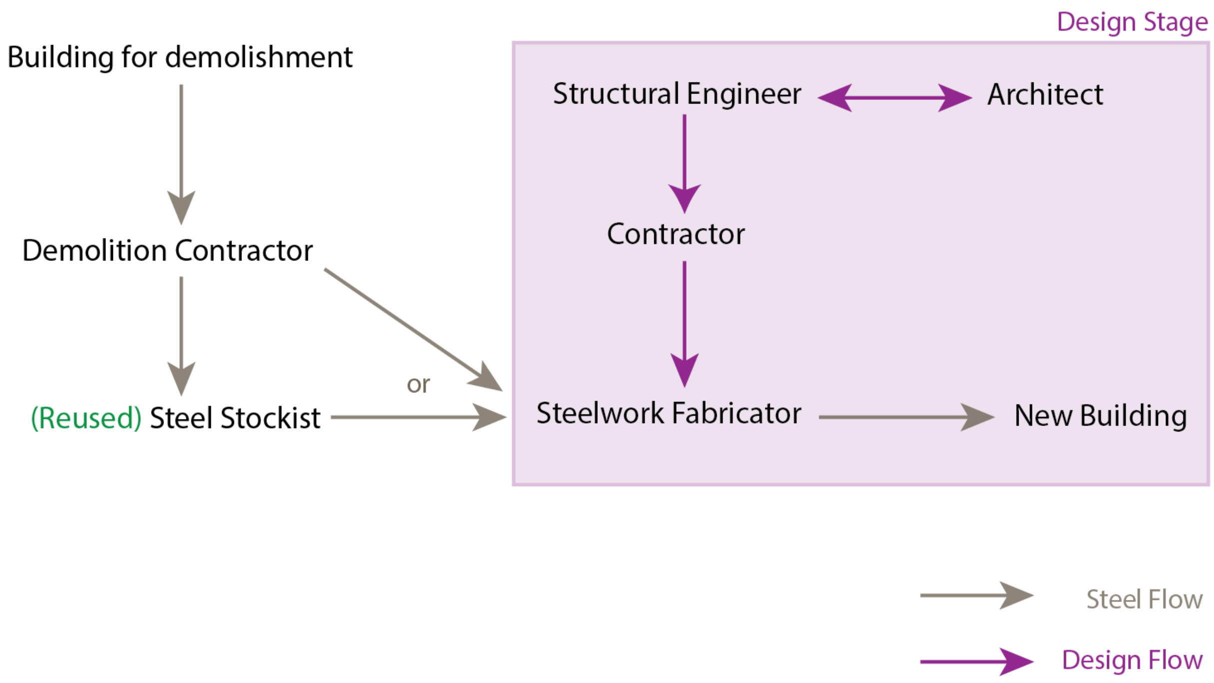

Figure 1: Mapping steel reuse flows for relocated reuse

3 State of the Art

A number of studies have investigated different aspects of steel reuse, including: current reuse rates; case studies with assessments of embodied emissions savings; barriers, and the potential costs or profits. This section summarises the key findings from this varied literature.

3.1 Current and potential reuse rates in the UK

Sansom and Avery (2014) surveyed demolition contractors to estimate what percentage of steel from demolition sites is reused, recycled and sent to landfill in the UK. The authors estimate that in 2007, 5% of light structural steel and 7% of heavy structural sections/tubes were reused, both in situ and relocated, from demolition sites. They show this is a 5% reduction in reuse rates relative to 2000 levels. However, it is challenging to accurately compare reuse rates across years due to differences in sample sizes, dictated by interviewee response rates and project types among demolition contractors. Cooper and Allwood (2012) suggest that it is possible to reuse 50% of cold formed sections, indicating significant technical potential to increase reuse rates.

3.2 Structural Steel Reuse Case Studies

Gorgolewski et al. (2006) document a series of relocated reuse case studies, predominately in Canada, where individual steel elements and components (roof trusses) had been reused. This shows barriers to reuse can be overcome under certain market conditions.

Pongiglione and Calderini, (2014) conduct a study to explore the potential material savings by reusing steel in the theoretical development of a train station in Italy. The authors identify that steel could be sourced from a nearby industrial building, suited for deconstruction but unsuitable for renovation. The authors show that around 30% of the new steel could be replaced by reused steel with only a small modification to the station design. This equalled a reduction of approximately 2915GJ and 138 TCO_2e in embodied energy and carbon respectively. The latter two estimates are highly dependent on the datasets used, making the material percentage saving of more interest.

Although this study is useful in demonstrating the potential environmental benefit of reusing steel, it is largely theoretical and does not explore the practical barriers to achieving these savings.

Ness et al. (2015) discuss the potential for new technologies such as radio frequency identification (RFID) and Building Information Modelling (BIM) to enable greater reuse of steel. They argue that these technologies enable increased traceability as relevant data can be stored over the building lifetime to unlock the residual steel at end-of-life. Using a case study of a former manufacturing plant, the authors estimate that reuse rather than recycling can reduce the embodied energy of a future construction project by 9.98MJ/kg of steel. However, the high costs involved in maintaining a RFID readability or a BIM model over the life of a building, may prevent the uptake of this strategy, given a visual inspection and creation of a deconstruction plan is a potentially low cost option. Akbarnezhad et al. (2014) also highlight the potential role BIM could play in improving future reuse rates.

3.3 Barriers to Reuse

Potential barriers to reuse (as well as design for deconstruction) are documented by Densley Tingley and Davison (2011), who review and synthesise the barriers to reuse identified in engineering, management and architectural literature, including: Addis & Schouten (2004), Dolan et al. (1999), Guy and Ciarimboli (unknown date), Hurley et al. (2002), Morgan & Stevenson (2005), Storey & Pederson (2003), and Moore (2010). These papers largely focus on design guidance and in doing so explore barriers to reuse. In total, twenty-four barriers were identified, with six barriers most commonly cited, suggesting these may be the most significant. These are: the perceived risk in specifying reused materials; cost: reuse could be more expensive; composite construction (for structural steel: concrete and metal deck flooring with shear studs connected to steel floor beams); lack of reuse markets and supply chains; time constraints which favours demolition over deconstruction; and inaccessible/irreversible joints. Hosseini et al. (2015) considers barriers to reuse as part of a broader review of the academic literature focusing on the challenges of introducing reverse logistics in the construction sector. The author identifies a total of 20 barriers, distinguishing between industry-specific barriers g. buildings not designed for easy dismantling and organisational barriers, e.g. time constraints. Many of the same barriers as outlined above were identified, although the relative significance of the barriers was not explored.

A publication from the International Council for Research and Innovation in Building and Construction (CIB, 2014) provides overviews of the barriers to deconstruction and reuse/recycling in a number of countries. For steel construction in Japan and the USA, longer deconstruction times were perceived as the major barriers, while in Canada, a key barrier was the complexity of recertifying structural steel. Guy (2011) reports the perceived challenges of reusing materials from a survey among architects and designers in the USA. Constructability was considered the greatest barrier by those with experience of reuse while lack of client interest was perceived to be most significant barrier by those with no experience. As this research was conducted in a high level large survey it did not delve into the perceived reasons for these challenges.

These reported barriers reflect the operating conditions at the time when these studies were conducted, they may however change over time. Uncertain structural properties of reused steel are cited as a barrier to reuse, often requiring destructive testing to determine tensile strength and thus steel grade. However, Fujita & Masuda (2014) outlines an evaluation flow for inspecting steel members in existing buildings and determining their suitability for reuse, describing several non-destructive tests, including portable ultrasonic and rebound-type hardness testers and a portal optical emission spectrometer, which can assess chemical composition. To progress steel reuse, this framework and technology could be developed into a low cost commercial offering.

3.4 Costs and Potential Profitability of Reuse

Demolition contractors in the UK currently sell scrap steel for recycling. However, revenues are dependent on a fluctuating scrap price. In 2015 this ranged between £100-£160/tonne (letsrecycle.com, 2015). However, Allwood et al. (p.225, 2012) show that under certain economic and technical conditions, deconstruction and reconditioning can be profitable. In their 2009 case study this was in the region of £100/tonne, although they didn't include any information on certification costs. Generally, the profitability of reuse will be dependent on the relative prices of steel scrap and new steel and the cost structures of companies involved in deconstruction and reconditioning. Of particular importance are the marginal labour requirements of deconstruction compared with demolition and the impact this has on the company wage bill. One consideration for demolition contractors considering deconstruction, is the lack of guaranteed demand for reused steel, whereas there is a clear demand for scrap steel. Vulotic (2013) discusses the potential of a web-based exchange portal for reused steel where demand could be demonstrated, he concludes that the business case for this would need developing, but it could be an effective mechanism to stimulate steel reuse.

Analysis by Geyer & Jackson (2005) suggests that reused supply chains face a number of constraints, including limited feasibility of deconstruction and re-fabrication, and limited market demand for re-fabricated sections. These affect the potential profitability and scale of steel reuse, whereas recycling supply chains do not face these constraints. Furthermore, the authors speculate that the profitability of reuse would diminish as so-called 'easy win' buildings most suited to deconstruction would occur first. Potential cost savings would then decrease as deconstruction and re-fabrication become technically more challenging and it may be preferable to demolish rather than deconstruct. This implies that for the existing building stock there is an economically-informed limit to deconstruction and reuse potential.

3.5 Conclusions from literature review

Existing literature demonstrates that there are material and emissions savings from steel reuse. The case studies show that steel reuse it is both technically and economically feasible under certain market conditions. However, these examples are largely anomalous in the UK which is experiencing declining rates of reuse. Exploration of barriers to general material reuse give a global view, with the following six barriers most commonly cited: perceived risk in specifying reused materials; financial constraints; composite construction; lack of a reuse market and supply chain; time constraints and restrictive joint types. These studies do not all focus specifically on steel, though there are a number of relevant insights. A small number of studies focus on barriers to reuse in different countries but no studies were found which examined the UK context. The UK is a particularly relevant case study for steel reuse, as on average, steel construction accounts for 65% of the market share for multi-storey construction (Steel Construction.Info, 2016 a) and 90% of the market for single storey industrial buildings (Steel Construction.Info, 2016 b). Finally, the views of different members of the design team (Figure 1) have had little exploration, particularly structural engineers and contractors. These two groups are critical in realising structural steel reuse as they are most likely to take on any associated liability risk.

This paper builds on this existing work and explores the specific barriers to structural steel reuse, focusing on the UK market, and sampling across the delivery supply chain in order to understand real and perceived barriers and who might be impacted by them. It is important to understand what different design team members perceive as the major challenges, as this may influence how they approach and respond to reuse opportunities. Building on this, recommendations to overcoming the identified barriers are identified and discussed with a view to facilitating increased steel reuse in the UK.

4 Method

A series of semi-structured interviews were conducted with a range of practitioners across the UK construction supply chain to gather information on the barriers and benefits experienced and perceived when reusing structural steel. Interviewees were identified through a range of techniques, including approaching experts at the 2014 annual Steel Construction Institute event, contacting known professionals in the construction industry and finally through snowballing – whereby interviewees identify other experts to participate. Interviewees were a mix of those with experience and without experience of steel reuse. The interviewees were predominately structural engineers, contractors and fabricators as these are the stakeholders responsible for specifying and deploying reused steel on new construction projects. Two architects were also interviewed to gauge wider design team perceptions on steel reuse. Efforts were made to select a representative sample of companies across the supply chain.

A semi-structured interview technique was selected as a set series of questions enabled consistency and comparable interview responses, and further questioning could be conducted to gain deeper insights where appropriate. It is acknowledged that there are potential drawbacks to semi-structured interviews, Opdenakker (2006) summaries some of the advantages and disadvantages of different interview techniques, highlighting that semi-structured interviews in particular require the interviewer to be very focused on the questions asked and answers given as the conversation may be more fluid than a full structured interview. The interviewer should also be aware not to direct the interviewee through social or verbal cues. A pre-prepared set of twelve questions was developed in advance of all the interviews which varied depending on whether the interviewee had experience or not of steel reuse. The question set for those without experience consisted of thirteen sub-questions, and the set for those with experience had twenty-one sub-questions. The additional questions for those with experience were project specific, to gather both case study insights and the interviewees' experience of reusing steel on these project. A complete list of interview questions can be found in the Supplementary Information for this paper.

The questions were structured around barriers to structural steel reuse. Three different interview techniques were employed: an unprompted discussion, a prompted discussion, and prioritisation of the barriers. An initial *unprompted* discussion allowed interviewees to respond, without being led, with their first impressions on what the barriers were to reusing steel. Following this, interviewees were asked to consider a list of barriers compiled from literature, identifying if each would be considered a barrier to structural steel reuse in the UK. To gain an understanding of the perceived significance of each barrier, interviewees were asked to reflect on the previous two rounds of questions and identify the three most significant barriers to steel reuse (*prioritised barriers*). From this, they were requested to consider methods of overcoming these barriers. The interviews continued with a broader discussion of any personal experiences with reusing steel, where relevant. The interviews concluded with a series of forward-looking questions on the future potential of steel reuse and the role of design for deconstruction. The interviews lasted between 60-90 minutes and were mainly conducted face-to-face with exception of four interviews, which were conducted via telephone due to time and location constraints. Table 2 provides anonymised details on interviewees including their current company roles, experience of steel reuse and how the interview was conducted. For the analysis, the interview responses were thematically coded, based on knowledge of the relevant literature, grouping similar responses together so the frequency of occurrence could be assessed.

Interviewee No.	Company Category	Role	Experience of Steel Reuse	Interview Type
1	Contractor	Principle Engineer	No	Face to face
2	Contractor	Head of Sustainability	Yes – in-situ	Face to face
3	Contractor	Engineer	Yes – relocated	Face to face
4	Contractor	Senior Design Manager	No (considered but not implemented)	Face to face
5	Structural Engineer	Structural Engineer	Yes – relocated	Telephone
6	Structural Engineer	Senior Engineer	Yes – in-situ	Face to face
7	Structural Engineer	Senior Engineer	No	Face to face
8	Structural Engineer	Senior Engineer	Yes - relocated	Telephone
9	Fabricator	Safety, health and environmental director	No	Telephone
10	Fabricator	Technical Advisory Engineer	Yes - relocated	Telephone
11	Fabricator	Senior Design Engineer	No	Face to face
12	Architect	Architect	Yes – in-situ	Face to face
13	Architect	Architect	Yes – in-situ	Face to face

Table 2: Interviewee Information

5 Results: barriers to and benefits of structural steel reuse

This section summarises the key findings from the interviews. It is split into four sub-sections, the first three deal exclusively with barriers to structural steel reuse, distinguishing between the unprompted, prompted and prioritised barriers, covered in sub-sections one to three respectively; the final sub-section discusses the perceived benefits of structural steel reuse.

5.1 Interview Results: unprompted barriers

This section outlines interviewees' unprompted responses to an open question 'what do you think are the main barriers to structural steel reuse?' Interviewees were also asked to explain why they perceived this as a barrier. The results are summarised in Figure 2, and outlined below.

'Supply chain dynamics and availability of reused structural steel', was the most frequently mentioned barrier by nearly two thirds of interviewees. One contractor summarised this barrier as the challenge of ensuring that '*the right steel is available in the right part of the country, when the client wants it, and quick enough*'. The requirement, therefore, is that reused steel is as easy to source as new steel, and incurs minimal risk of project delays. However, there is a strong perception that this is not currently the case. Six interviewees stated they were unsure where you would source reused steel from, and were sceptical that appropriately sized steel would be available. Concern over potential 'additional costs' from reused steel was also flagged as a barrier (when in the project timeline these costs might occur is discussed further in section 5.2). A 'lack of awareness' about reused steel across the supply chain was the third most frequently mentioned unprompted barrier. 'Lack of client demand' was also highlighted as a barrier by three interviewees, suggesting that clients are perceived as a key driver of steel reuse. 'CE marking' (introduced for fabricated steelwork in the UK from July 2014), 'traceability/certification', and 'design team buy-in' were all mentioned as barriers by three different interviewees. Seven more barriers, as shown in Figure 2, were also proposed by one or two interviewees, implying these are less significant or immediately obvious than those barriers more commonly discussed.

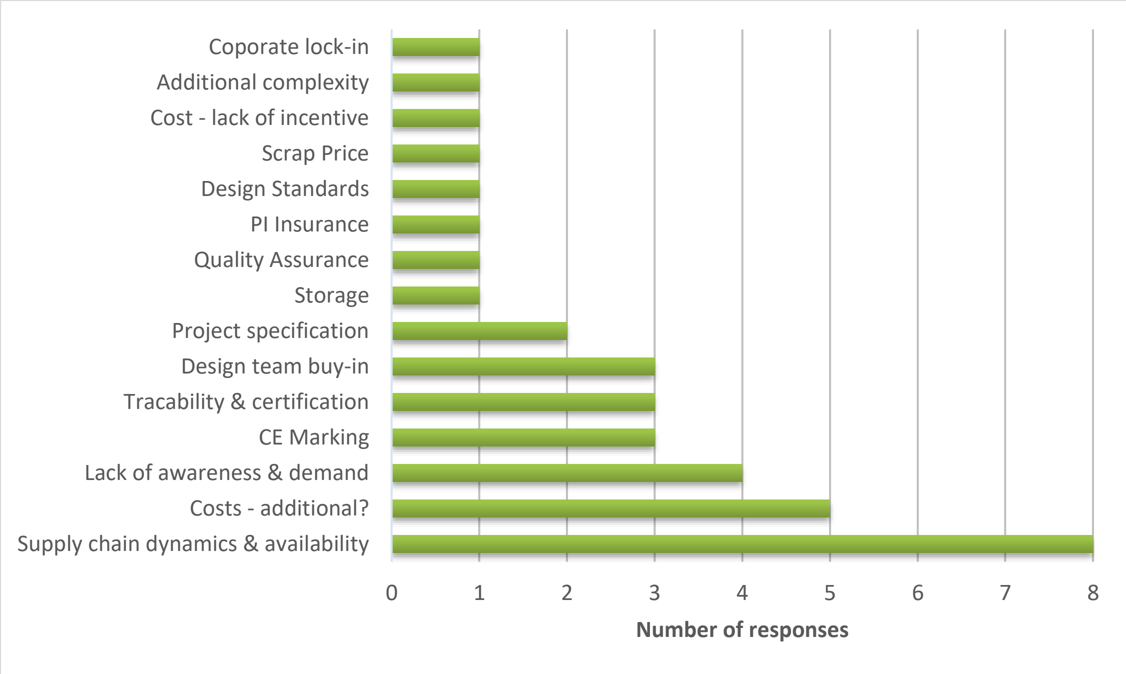

Figure 2: Respondents view of barriers to structural steel reuse, from the unprompted discussion

5.2 Interview Results: prompted barriers

After the unprompted discussion, interviewees were asked to review a list of barriers compiled from existing research, on structural steel reuse and indicate if they perceived these barriers to exist when reusing structural steel in the UK. For each barrier, interviewees were asked to explain their answer. Figure 3 shows the results of these discussions from twelve interviews, (due to restricted interview time one interviewee was not asked this question). Six barriers were identified by ten or more respondents, suggesting that these are the most commonly perceived barriers:

- Lack of client demand
- Lack of supply chain coordination and integration
- Storage of recovered materials
- Construction sector inertia
- Lack of information about existing structure and materials
- Jointing technique

'Lack of client demand' was almost unanimously considered a barrier. It was suggested that if more clients requested reused steel, the market would change significantly and the design team would work together to achieve steel reuse. Although one architect suggested that lack of client demand is '*not so much of a barrier, but more of a lack of incentive*'. In addition, interviewees recognised that if overcome, this current barrier could become a driver of future reuse. 'Lack of supply chain coordination and integration' was a frequently identified barrier. When invited to explain further, there was little consensus regarding who would procure and supply reused steel. Two interviewees indicated that this might be a role for a new stakeholder, not currently operating in the construction supply chain. Linked to this, is the need for 'storage of recovered materials'. Interviewees proposed that to match supply and demand, elements would likely need to be stored for a period after salvage. Further research could analyse the steel stockholding capacity in the UK, undertaking discussions with current industry players to ascertain the likelihood of them expanding their product offering to include reused steel. Inertia in the construction sector and unwillingness to deviate from business-as-usual practices was also highlighted as a barrier. One interviewee stated that '*things get put in the "too-difficult-box"*' while another remarked that inertia is driven by cost, as '*changes from* *business as usual could result in cost increases'*. However, many respondents did feel that this particular barrier could be mitigated with increased client demand, as the supply chain can and does effectively respond to this. A lack of information about the existing structure and recovered materials was considered by many to be a barrier, although several interviewees thought this could be overcome by testing (which might incur minimal costs) and improved in the future through asset tagging. Testing was also thought to overcome the barrier of a 'lack of performance guarantees for reused materials', another barrier highlighted.

'Jointing technique', largely welded connections for steelwork was thought to be a barrier by many respondents as the steelwork would have to be cut out. However, some posited that this still might be the fastest way to deconstruct a building and wondered if the steel would still be reusable if carefully cut out. Other concerns were raised regarding the additional time required for deconstruction, as this would increase costs. 'Inaccessible joints' were also thought to be a barrier for this reason, in addition to limiting reuse potential. In contrast, 'composite construction' was thought to be a barrier by only half the respondents, with one contractor stating that it just affects *'what percentage yield you could get out of the structure'*.

Concerns about additional costs were considered a barrier in the unprompted discussion, and in this prompted discussion, these costs were defined further. Two thirds of respondents thought that additional design costs and increased deconstruction costs would be barriers; while five thought insurance costs could be a problem. Although there was debate as to whether it might be personal indemnity insurance, or collateral warranties that would be affected; four respondents were uncertain if this was a barrier as it could be overcome by testing and traceability of steel. The impact on project programme due to additional deconstruction time, including associated costs, was perceived as a barrier by only a third of interviewees. One contractor stated that '*programme is just perception'*, and an architect thought that deconstruction could easily be factored into a project if it was a known at the beginning of the project. Fabrication costs were also thought to be a barrier by a third of respondents, with two fabricators saying it '*should be like any other job as long as you know the steel grade'*, and the third stating that it '*would be dependent on the building'*. Only a quarter thought material costs would be a barrier. One respondent even speculated that '*in theory it [reuse] should be cheaper*'. No interviewees proposed 'prohibitive domestic policy', 'access to finance' or 'competition' as barriers to structural steel reuse. 'Competition' was thought to be a driver for reuse. Seven respondents suggested that that knowledge and experience of steel reuse would make them more competitive during tenders for certain clients.

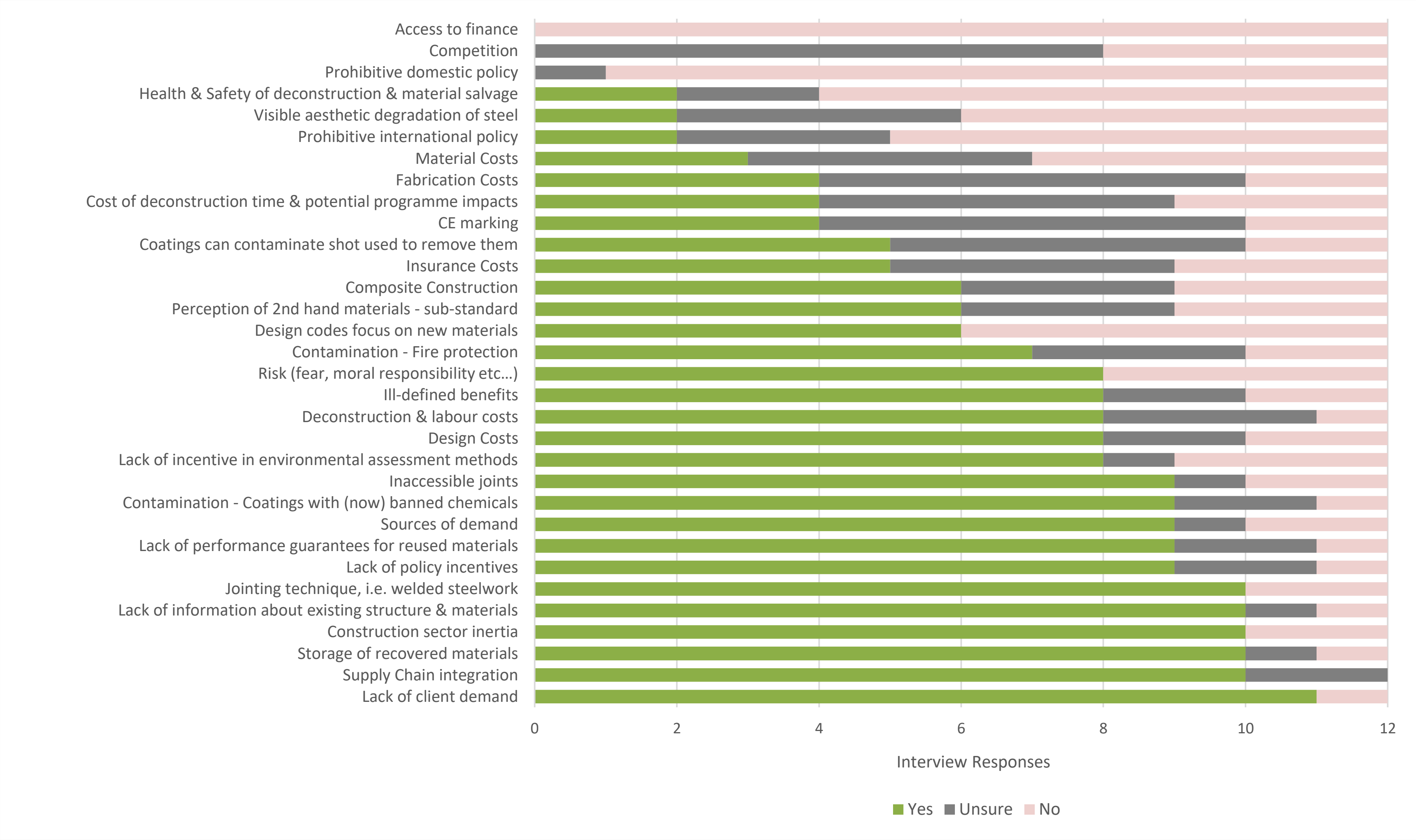

Figure 3: Prompted interview results, from left to right: yes, maybe and no responses to suggested barriers

5.3 Interview results: prioritised barriers

The next section of the interview focused on prioritising barriers. Interviewees were invited to consider which barriers, both prompted and unprompted, were the most significant for the construction supply chain and how they might be overcome. In total, eleven different barriers were highlighted, as listed in Table 3. The three top barriers were 'cost' (although it was thought this would reduce over time due to economies of scale); 'availability and storage'; and 'no client demand/client perceptions'. 'Quality assurance and traceability' and 'gaps in the supply chain' were also identified by a quarter of interviewees as major barriers. These barriers are all largely systemic across the construction sector rather than technical engineering barriers.

Barrier	Responses of top 3 barriers	Options to overcome the barrier
Cost	6	- Good case study projects to demonstrate what works and the benefits
General	(3)	- Economies of scale & shift to more reuse would mean the market would likely drive the cost down - Government incentive to kick-start industry, either subsidise or create shared storage facility, making availability known
Deconstruction	(2)	- An assessment to show costs are worthwhile & potential scalability
Shot-blasting	(1)	- Might be more economical if done at scale
Fabrication	(1)	- Reused steel would need to come into the shop the same as new sections, economies of scale might help this
Availability & Storage	6	- Network of suppliers/procurement options required & clear availability - Create links between demolition contractors & stockists, but for business to change would need to know there is demand - Make it clear what is available, there needs to be an equivalent of the blue book on designers' desks, although this could be in a website form - Need demand to incentivise demolition contractors to deconstruction and salvage; & a list of suppliers of reused steel - On-site testing to speed up process
No client demand & client perceptions	4	- Paperwork/testing to show quality of reused steel - Government leadership in their procurement could stimulate a change - Showing reuse can be cost effective - Show potential for 'green' marketing
Quality assurance & traceability	3	- Testing & clear guidance required - Need to better understand the steel reuse process
Supply chain gaps & lack of supply chain integration	3	- Need to incentivise deconstruction, show demand/financial gain to supply chain so gaps to deconstruct, store & test reused steel are filled by those who see a business opportunity
No clear financial incentive	2	- Client demand & better understanding of economic viability - Policy incentives, or credit in environmental assessment methods
Inertia in the construction sector	2	- Education & clear guidance for reuse would support change - Need to show a clear financial gain/incentive to get industry to change from business as usual
Impact on design	2	- Prevent reuse dominating a project, balancing environmental factors with client requirements - Consider when reuse is introduced, giving clear guidance for reuse - so whole supply chain can facilitate & meet a defined good reuse practice
Lack of designer knowledge	1	- Clear guidance for reuse, as well as educating the sector about steel reuse as an option, technical case studies
Lack of incentives	1	- Incentives for stockists - financial; clients - help with planning, or environmental assessment credit; deconstructing buildings - incentive needed here too
Lack of defined benefits	1	- Highlight and document the benefits, & give guidelines for when reuse is most beneficial

Table 3: Top barriers to structural steel reuse as identified by interviewees

5.4 The benefits of steel reuse

The final part of the interviews dealt with potential benefits from reusing steel. All interviewees identified some benefits associated with reusing steel. Many focused on the environment benefits, including, reduced embodied carbon and energy, reduced use of virgin materials, and improved sustainability. One respondent simply stated that it is '*the right thing to do'*. The potential for growth of a reused steel market was also perceived by one respondent as a benefit for 'UK Plc', and several discussed the marketing benefit of reducing embodied carbon through increased steel reuse. All interviewees stated that they would consider reusing steel in future projects, and the two contractors and two structural engineers who had experience reusing steel (in-situ, component reuse; and re-located, element reuse) all said it was a positive experience.

6 Discussion

This section discusses the barriers according to interviewee's experience and role. It also compares the interview findings to those barriers from existing literature and discusses the emerging themes to overcome the significant, systemic barriers identified through interviews. Four, non-exclusive, complimentary options are identified to overcome the barriers highlighted by interviewees. These are: (1) the creation of a database of suppliers/reused section availability, (2) a clear demonstration of client demand, (3) technical guidance and education for the construction industry, and (4) government leadership. These suggestions will be discussed further in sub-sections 6.2 to 6.5.

The major barriers were mapped across the supply chain to explore if there was any correlation between place in the supply chain and perception of the significant barriers. There did not appear to be any strong correlations, although this may be due to small sample size. The only exception to this is that responses about quality assurance and traceability were all from either contractors or steelwork fabricators. This is unsurprising given they're likely speaking to their perception of carrying the majority of this risk. However, all the other major barriers discussed were distributed across the supply chain.

The barriers were also mapped across those six interviewees who had successful experience of steel reuse (four in relocated reuse, two with in-situ reuse). This yielded only one correlation: the three interviewees who felt that there was a supply chain gap, all had experience of steel reuse (two relocated, one in-situ).

6.1 A comparison of barriers to structural steel reuse between literature and interview stages

A comparison was made to show how barriers from literature compare with the top barriers across the interviews stages, as shown in Table 4. From interview stages, the top five prioritised barriers are compared to the top six unprompted and prompted barriers, with the percentage of respondents citing each barrier shown. This was to explore if and how interviewees' understanding of reuse evolved as they considered how it would affect them and how the entire supply chain might need to adapt. Across the stages there was some variation in the frequently discussed barriers, however, all major barriers were picked up as common barriers in either the unprompted or prompted discussions – or in some cases both (client demand and availability/storage). In the prompted barriers discussion, cost was broken down into different areas, e.g. design costs and material costs, thus cost overall wasn't one of the most commonly identified prompted barriers due to a lack of consensus on which potential cost would be the biggest barrier.

Furthermore, there is a marked difference between those barriers most commonly discussed in literature to those highlighted as major barriers in the interviews, with only two common ones: 'cost' and 'supply chains gaps & lack of integration'. There is a parallel with the study by Guy (2011) who reported whose with no experience of reuse felt that a lack of client interest was a significant barrier. This ties with the views of 33% of respondents in this study that no client demand is a significant barrier. However, the most of the frequently raised barriers in the literature. e.g. jointing, composite construction and time for deconstruction, when discussed with respondents were felt to limit potential recovery of reused materials but weren't actually perceived as preventing reuse in the industry. Although, limited recovery could limit the scale of availability of reused sections, which could limit reuse if demand was sufficient to exhaust the more readily recoverable steel sections. However, this scenario is only likely to arise with significantly increased reuse rates. The interviews with practitioners conclusively highlighted overarching, systemic barriers such as cost, availability/storage, no client demand that need to be addressed to facilitate steel reuse. Understanding and overcoming these systemic barriers should have a significant impact in improving steel reuse. The four identified options to overcoming these systemic barriers, as highlighted at the start of the section, are discussed in the following sub-sections.

Barrier	**Literature**	**Semi-Structured Interviews**		
		Unprompted	**Prompted**	**Top Three**
Cost		42%		50%
Availability/Storage		67%	83%	50%
No client demand		33%	92%	33%
Traceability		25%		25%
Supply chain gaps & lack of integration			83%	25%
Inertia			83%	
Lack of information about reused materials			83%	
Jointing technique			83%	
CE Marking		25%		
Design team buy-in		25%		
Risk				
Composite Construction				
Time constraints for deconstruction				

Table 4: Comparison of top five-six barriers from literature and across the interview stages, with the percentage of interviewees who highlighted the respective barrier shown

6.2 A database of suppliers and section availability for reused steel

Where to source reused steel from and uncertain availability was identified as a key barrier by many interviewees. However, this barrier would only apply to relocated element and component system reuse. A database of suppliers was commonly mentioned as a method to overcome this barrier. Furthermore, knowledge of which sections are available would remove any uncertainty about supply. There are already reclamation yards in the UK, and many of these have a website showing availability of materials. However, it might require a large amount of time to source materials in this manner and a review of these sites by the authors revealed very few structural steel sections were available. Procurement in a similar manner to that of new sections would be an easier adjustment for the supply chain. One option would be the introduction of a new player within the steel reuse supply chain, that of a reused steel stockholder, as suggested in Figure 1. Existing stockists could also expand their offering to include reused steel. This would provide clarity in sale and procurement routes for the supply chain. If a database of reused stockists was maintained, they could be contacted to ascertain stock availability, or this could be listed on websites, as suggested in Vukotic (2013). However, steel stockists are unlikely to emerge until there is a clear business benefit and demand for reused steel, the simultaneous development of these will likely take time. Thus, short-term transition solutions to facilitate increased reuse and overcome some of the initial barriers will likely be required. These will be intrinsically linked to a demonstrable increase in demand for reused steel, as discussed in the next section.

6.3 The feasibility of demonstrating a demand for reused steel

A key barrier discussed throughout the interviews was insufficient client demand for reused steel. However, one contractor stated that there are '*some clients who would love to do it, but it's too big a risk to demand it*'. This suggests that some clients are not only receptive to the idea but actively want design teams exploring it as an option. With growing awareness across the construction sector of the significance of embodied carbon, material efficiency and the circular economy, the reuse of materials is gaining visibility, increasing the likelihood of increased demand for reused steel. However, demand will need to be clear and the market conditions right for demolition contractors to alter their business model to deconstruct and salvage materials. This move into deconstruction, under the appropriate cost conditions, would enable demolition contractors to expand into new markets and could provide increased revenue.

For this to work there would need to be a mechanism for designers, contractors and clients to show a demand for reused steel, enabling demolition contractors to respond and supply it. A web-portal that matches the supply and demand for reused steel would be an effective mechanism to achieve this. Such a web portal, Planet Reuse (2015), exists in the USA for all reused materials, where users state if they have reused materials or want reused materials. Funding has been obtained to explore the feasibility of a more specialised reuse web-portal for relocated steel elements and components in the UK; Figure 4 shows how this web-portal might work.

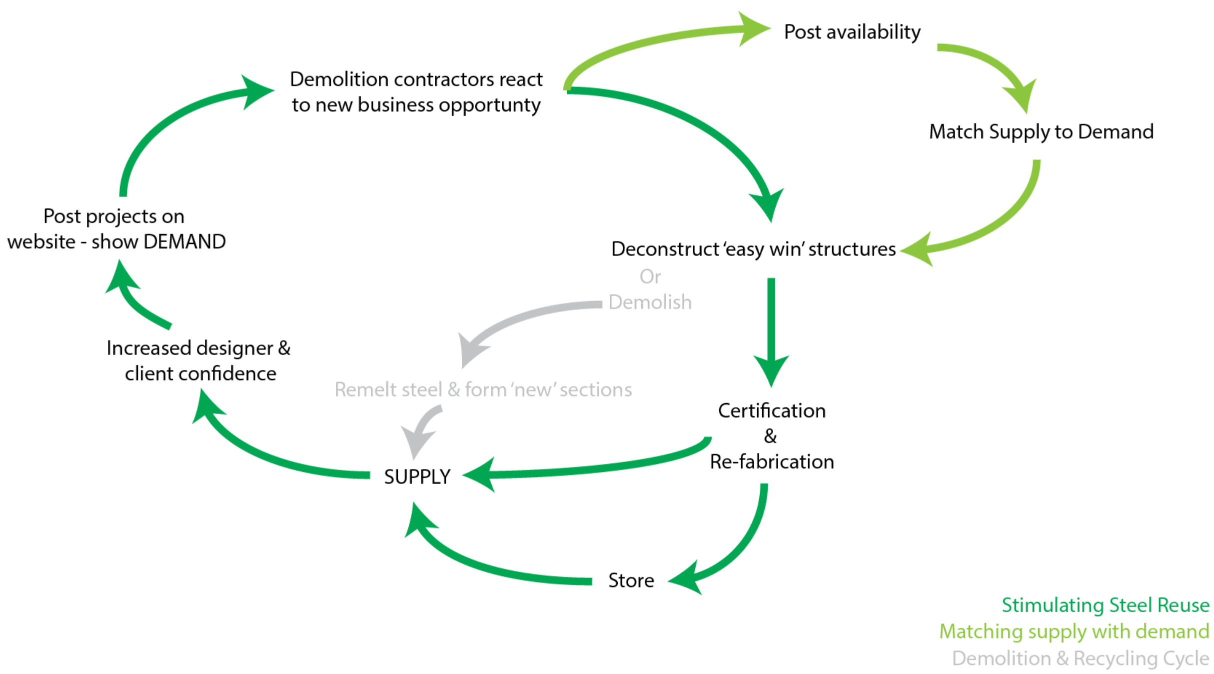

Figure 4: Matching supply and demand of reused steel

6.4 Guidance and education for reused steel

In the interviews there was consensus that there's a lack of guidance for reusing steel, particularly around design and testing requirements. This may partly explain the lack of industry awareness that steel reuse is a possible option. Targeted steel reuse guidance and education for clients, structural engineers, architects and contractors were suggested to overcome both of these barriers; for example via information documents, webinars, seminars, or built into Continuing Professional Development (CPD).

The multifaceted benefits of reusing steel, discussed in section 5.4, should also be highlighted in industry guidance documents so it is considered more often as an option. This should build on existing work by Bioregional and WRAP; for example 'The reclaimed building products guide' (2008), which quotes a BRE environmental profile, showing reused steel has a 96% environmental impact saving compared to 'new' steel (with 60% recycled content). There is a risk of inefficient reuse of steel due to overly conservative design and potential difficulty in sourcing specific sections. Guidance should therefore explain this risk with a view to reducing it and encourage early sourcing where possible.

Building on this, detailed guidance is required on the process of designing with reused steel. A set procedure for testing (destructive and non-destructive) would be useful, with a list of suitable test houses. Ideally, this guidance should be developed by, or in conjunction with, an industry body, for example the Steel Construction Institute (SCI) or the Institute of Structural Engineers (IStructE) in the UK, to give credibility across the construction sector. Guidance should also be given on the applicability of CE marking; taking the form of a published common understanding from the industry associations to overcome this potential barrier and remove uncertainty for the industry. The suggested guidance would enable more designers and contractors to confidently reuse structural steel.

6.5 The role of Government

Government intervention to increase structural steel reuse could take many forms. Softer initiatives might include: setting up a registry for suppliers of reused steel; information sharing; awareness raising; and recognition for projects leading steel reuse, for example through industry awards. These initiatives should be launched in conjunction with industry associations who are focused on improving the sustainability of construction, or joint government and industry initiatives, such as the Green Construction Board.

Local governments could incorporate design for deconstruction objectives into local planning regulations in order to increase the future amount of reused steel available. One option to increase the steel available for reuse locally would be to require all buildings that register for demolition to have a pre-demolition audit to ascertain what materials could be salvaged, there is already a standard procedure for this and they can be carried out as part of BREEAM certification (BRE, 2015). If there are substantial carbon savings to be made, over a minimum threshold, there could be a notice issued by the Local Authority Building Control requiring deconstruction and material salvage. Central government could also be involved to standardise the approach.

Central government could also catalyse demand through public sector procurement rules, specifying a percentage mass of all steelwork to be reused. There is already a precedent from 'Insights from the Government Buying Standards' determining that, as a minimum, all new builds in Government Estate achieve a BREEAM excellent rating (BRE Global, 2015). In 2013, public funded construction was £20bn, accounting for 37% of the value of all new projects in the UK (ONS, 2014). Cooper et al., (2016) use input-output techniques to estimate that the construction sector spent £1.7bn on steel in construction in 2011. Assuming that 37% of this steel expenditure goes into public funded construction projects and if hypothetically the price of reused steel is 10% lower than new steel, and just 5% of new steel is replaced with reused steel, there could be savings of around £3m. If implemented, this level of demand should reduce design and certification costs through economies of scale, would raise awareness across the construction sector, increase designer/contractor confidence and encourage increased deconstruction of buildings to supply reused steel to public sector projects.

The UK government also has the option to provide fiscal incentives to stimulate and support new business development related to reuse; for example subsidising the storage of reused steel. However, this is unlikely to occur in the current political climate unless an initiative is designed to be fiscally neutral. Furthermore, reuse has not received much government interest to date in spite of the potential macroeconomic benefits. For example, reuse would help reduce the trade deficit in steel products, valued at over £230m in 2014 (estimated from HMRC, 2015). It has also been shown by Cooper et al. (2016) that reuse has the potential to lead to a modest increase in domestic employment in the construction sector supply chain, as deconstruction is more labour intensive than demolition. Possible reasons for the current lack of government interest are: the legislative focus on operational rather than embodied emissions, lack of awareness around steel reuse as a viable emissions reduction strategy, and a general reluctance to legislate and thus overtly intervene in a sector which is so critical for future UK economic growth (BIS, 2012).

Going forward, as GHG mitigation efforts increase, it is likely that the UK construction sector will face increasing a carbon price, either in the form of carbon taxes or emissions trading systems (World Bank, 2016). If sufficiently high it may be more profitable to use reused rather than virgin or recycled structural steel. Although, this will depend on the extent to which the steel price varies independently of a carbon price, and the cost of reuse versus purchasing new steel.

7 Conclusions and Next Steps

To understand the opportunities and barriers to structural steel reuse in the UK, a series of semi-structured interviews were held with participants from across the UK construction supply chain. Interviewees identified the following barriers as being most significant: cost, availability/storage, lack of client demand, traceability of steel, and supply chain gaps/lack of coordination. These barriers are systemic and thus require a coordinated approach and interventions across the supply chain. A key conclusion is that some of the barriers highlighted in this paper differ from some of those most commonly discussed in literature: cost, supply chain gaps/lack of integration, risk, jointing technique, composite construction and time for deconstruction. The latter three barriers in particular are technical barriers that will reduce the practical recovery rate from specific buildings that face these challenges. This may, in the long term, limit availability once 'easy win' buildings have been deconstructed, but, as identified in the interviews, systemic barriers such as cost, supply chain gaps/integration and lack of demand present a more immediate and significant practical challenge for the UK construction industry that must be tackled first.

Derived from the interviews, four complementary mechanisms are proposed to overcome the systemic barriers, these are as follows: (1) the creation of a database of suppliers/reused section availability, (2) a demonstration of client demand (3) technical guidance and education for the construction industry and (4) government leadership. Further work is currently exploring a web-portal to match supply and demand, in order to address and implement mechanisms (1) and (2). Greater demand for reused structural steel should also stimulate changes in the demolition sector. Guidance and education for the construction sector, to improve confidence and skills in designing and building with reused steel, is also required, and should be supported by professional institutions. Further research and commercialisation of quick, cheap testing methods to demonstrate steel properties would also be beneficial, in order to demonstrate traceability and improve designer and contractor confidence in the grade and quality of procured reused steel. Future projects could also have the steel grade stamped onto structural steel to inform future designers. There is a role for government, at national and local level to show leadership in this area, in particular by encouraging pre-demolition audits and deconstruction, and through public procurement. The energy and GHG emissions saved and resources conserved make a strong environmental case for reuse, these were highlighted by interviewees as the major benefits of reuse. By implementing the recommended mechanisms, the identified barriers to structural steel reuse can be overcome, increasing steel reuse and thus enabling the benefits from reuse to be realised.

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9 References

Addis W and Schouten J (2004) Design for deconstruction – principles of design to facilitate reuse and recycling. CIRIA, London.

Akbarnezhad, a., Ong, K. C. G., & Chandra, L. R. (2014). Economic and environmental assessment of deconstruction strategies using building information modelling. *Automation in Construction*, *37*, 131–144. doi:10.1016/j.autcon.2013.10.017

BioRegional, 2008. The reclaimed building products guide. Published by: Waste & Resources Action Programme. Available at: http://www.bioregional.com/wp-content/uploads/2015/05/WRAPReclaimedBuildingProducts_May08.pdf [accessed 22/09/15]

BRE Global. 2015. BREEAM – Non Domestic – Government. Available at: http://www.breeam.org/page.jsp?id=343 [accessed 17/09/2015]

BRE Smart Waste. 2015. Pre-demolition and refurbishment audits. Available at: http://www.smartwaste.co.uk/predemolition-and-prerefurbishment-audits [accessed 05/04/16]

Business, Innovation and Skills (BIS), 2012. Industrial strategy: UK sector analysis. Available at: https://www.gov.uk/government/publications/industrial-strategy-uk-sector-analysis [accessed 30/11/15] URN 12/1140

Climate Change Act 2008 (2008) Elizabeth II. Chapter 27. The Stationary Office, London, UK. Available at: http://www.legislation.gov.uk/ukpga/2008/27/pdfs/ukpga_20080027_en.pdf [accessed 10/09/15]

Cooper, D., & Allwood, J. 2012. Reusing steel and aluminium components at end of product life. Environmental science and technology, 46, pp: 10334-10340.

Cooper, S., Skelton, A., Owen, A., Densley Tingley, D., Allwood, J. 2016. A multi-method approach for analysing the potential employment impacts of material efficiency. Resources, Conservation and Recycling, volume 109, May-June 2016, pp: 55-66.

Department for Environment, Food and Rural Affairs (DEFRA). 2015. UK's Carbon Footprint 2007-2012. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/414180/Consumption_emissions_Mar15_Final.pdf [accessed 03/11/15]

Densley Tingley, D. & Davison, B. 2011. Design for Deconstruction and Material Reuse, Proceedings of the ICE, Energy 164 (4) pp: 195-204

Fujita, M., & Masuda, T. (2014). Application of Various NDT Methods for the Evaluation of Building Steel Structures for Reuse. *Materials*, *7*(10), 7130–7144. doi:10.3390/ma7107130

Geyer, R., & Jackson, T. (2004). Supply Loops and Their Constraints: the industrial ecology of recycling and reuse. *California Management Review*, *46*(2), 55–73. doi:10.1016/S0161-6420(98)96023-7

Giesekam, J., Barrett, J., Taylor, P. & Owen, A. 2014. The greenhouse gas emissions and mitigation options for materials used in UK construction. *Energy and Buildings.* 78, 202–214

Gorgolewski, M., Straka, V., Edomnds, J., & Sergio, C. 2006. Facilitating greater reuse and recycling of structural steel in the construction and demolition process. Available at: https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/mineralsmetals/pdf/mms-smm/busi-indu/rad-rad/pdf/re-ste-fin-eng.pdf [accessed 28/08/15]

Green Construction Board. 2013. The Low Carbon Routemap for the Built Environment. Available at: http://www.greenconstructionboard.org/images/folder/GCB_Carbon_ROUTEMAP.pdf [accessed 02/06/15]

Guy, B. 2011. Design for reuse of building materials in the USA. Proceedings of World Sustainable Building Conference, October 18-21, 2011 Helsinki, Finland, pp: 491-501. Available at: http://site.cibworld.nl/db/publication/browserecord.php?-action=browse&-recid=1285 [accessed 16/08/16]

Guy B and Ciarimboli N (unknown date) Seattle guide: Design for disassembly in the built environment. Available at: http://your.kingcounty.gov/solidwaste/greenbuilding/documents/Design_for_Disassembly-guide.pdf [accessed 18/08/2010].

HM Government. 2013. Construction 2025, Industrial Strategy: government and industry in partnership. Crown copyright, URN BIS/13/955. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/210099/bis-13-955-construction-2025-industrial-strategy.pdf [accessed 02/06/15]

HM Revenue & Customs (HMRC), 2015. Data by commodity code. Available at: https://www.uktradeinfo.com/Statistics/BuildYourOwnTables/Pages/Table.aspx [accessed 30/11/15]

Hosseini, M.R., Rameezdeen, R., Chileshe, N., & Lehmann, S. 2015. Reverse logistics in the construction industry. Waste Management & Research, 33 (6) pp: 499-514.

Hurley J, Goodier C, Garrod E et al. (2002) Design for deconstruction – BRE technical opinions. In: Design for deconstruction and material reuse. Proceedings of the CIB Task Group 39: Deconstruction Meeting, Karlsruhe, Germany (Chini AR and Schultmann F ((eds). April 2002, CIB publication 272, paper 13.

International Council for Research and Innovation in Building and Construction Publication, ed. Nakajima, S. & Russell, M., 2014. Barriers for deconstruction and reuse/recycling of construction materials. CIB Publication 397. ISBN 978-90-6363-085-0

Letsrecycle.com, 2015. Ferrous Scrap Prices 2015. Available at: http://www.letsrecycle.com/prices/metals/ferrous-metal-prices/ferrous-metal-prices-2015/ [accessed 14/08/15]

Moore D (2010) Re-using metal without melting. Presentation in London, BCSA, 28 April 2010.

Morgan C and Stevenson F (2005) SEDA – Scottish Ecological Design Association. Design and Detailing for Deconstruction. See http://www.seda.uk.net/dfd/dfd.pdf [accessed 07/05/2010].

Ness, D., Swift, J., Ranasinghe, D. C., Xing, K., Soebarto, V., & Terziovski, M. (2015). Smart steel : new paradigms for the reuse of steel enabled by digital tracking and modelling. *Journal of Cleaner Production*, *98*, 1–16. doi:10.1016/j.jclepro.2014.08.055

Office for National Statistics (ONS), 2014. Construction statistics annual tables – table 2.4, No 15, 2014 Edition. Available at: http://www.ons.gov.uk/ons/publications/re-reference-tables.html?edition=tcm%3A77-360369 [accessed 30/11/15]

Opdenakker, R. 2006. Advantages and disadvantages of four interview techniques in qualitative research. Forum Qualitative Sozialforschung / Forum: Qualitative Social Research, [S.l.], v. 7, n. 4, sep. 2006. ISSN 1438-5627.

Planet Reuse. 2015. Available at: http://planetreuse.com/ [accessed 17/09/15]

Sansom, M. & Avery, N. 2014. Reuse & recycling rates of UK steel demolition. ICE Briefing, Engineering Sustainability, vol. 167, ES3.

Shankleman, J. 2015. Government demolishes zero carbon goal for new homes. Business Green, Sustainable thinking. Available at: http://www.businessgreen.com/bg/news/2417282/government-demolishes-zero-carbon-goal-for-new-homes [accessed 17/09/15]

SteelConstruction.Info. 2016 a. The market for structural frames – market shares. Available at: http://www.steelconstruction.info/File:Market_share.png [accessed 16/08/16]

SteelConstruction.Info. 2016 b. The case for steel. Available at: http://www.steelconstruction.info/The_case_for_steel [accessed 16/08/16]

Storey JB and Pedersen M (2003) Overcoming the barriers to deconstruction and materials reuse in New Zealand. In Deconstruction and material reuse. Proceedings of the 11th Rinker International Conference, Gainesville, Florida, USA (Chini AR ((ed)). May 2003, CIB publication 287, paper 23

Vukotic, L. 2013. Assessment of the potential for structural steel reuse in the UK construction industry. Dissertation for the degree of Master of studies in Construction Engineering. The University of Cambridge.

Webb, N., Broomfield, M., Brown, P., Buys, G., Cardenas, L., Murrells, T., Pany, Y., Passant N., Thistlewaite, G., & Watterson, J. Ricardo-AEA. 2014. UK Greenhouse Gas Inventory, 1990 to 2012. P.28 Available at: http://uk-air.defra.gov.uk/assets/documents/reports/cat07/1404251327_1404251304_ukghgi-90-12_Issue1.pdf [accessed 02/06/15]

World Bank. 2016. Carbon Pricing. Available at: http://www.worldbank.org/en/programs/pricing-carbon [accessed 19/08/16]