Real and perceived barriers to steel reuse across the UK construction value chain

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Abstract

Although steel reuse has been identified as an effective method to reduce the carbon and energy impact of construction, its occurrence is shrinking in the UK. This can be partly explained by the many barriers which have been identified in the literature, but a detailed analysis of how these barriers affect different parts of the supply chain is still lacking. We show that there is a contrast between perceived higher costs and time required to employ reused steel and the assessments of realised projects. Using a novel ranking method inspired from the field of information retrieval (tf-idf), we have analysed interviews of actors across the supply chain to determine the acuteness of the perception of each barrier. We show that demolition contractors, stockists, and fabricators face specific barriers which each need to be addressed at their level. This is in contrast with more generic barriers present throughout the value chain which we show are probably more perception than reality. Finally, we suggest how supply chain integration could facilitate reuse and make it economically viable at scale.

Keywords: Steel, Reuse, Barriers, Supply chain

1. Introduction

Despite considerable environmental benefits, steel reuse is a rare occurrence in the UK [1], and his becoming less common [2, 3]. There are a number of reasons for this:

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changes in the demolition practices, a more formalised certification process for the steel, and changing design practices [4]. Nonetheless, a number of case studies show steel reuse is possible and can yield substantial benefits in terms of cost and time, beyond the carbon savings. Replicating these successes requires understanding the circumstances behind them. If they could be replicated, steel reuse could be pushed from a marginal possibility to common practice. In this document, we define 'steel reuse' as the use in a new construction of an element obtained from the deconstruction of an older building, typically after testing and reconditioning.

Most studies of the environmental impacts of buildings focus on operational carbon emissions, notably the energy required for heating, cooling and lighting [5, 6]. However, studying only the operational aspects of buildings is insufficient to provide a complete understanding of the impact of construction, as energy and emissions are also embodied in the building materials and construction. Strategies to reduce embodied energy and carbon depend on the material choice for the frame [7]. Concrete framed buildings have relatively little scope for improvement, barring the introduction of novel substitution materials as the current production of supplementary materials is wholly exploited. Steel buildings by contrast offer an alternative route for carbon and energy savings: the steel elements of the building can be reused if the building is deconstructed rather than demolished. As the recycling of steel is an energetically expensive operation [8] even using the best currently available technology, the reuse route represents considerable savings over recycling [9]. Indeed, steel reuse can play an important part of a global strategy for the efficient use of materials [10, 11] as the carbon and energy embodied in structural frames can represent up to 20-30% of the assumed 50 year life-time carbon footprint of a building [7, 12]. Studies on the benefits of steel reuse tend to be prospective, focussing on how design for deconstruction (thought to facilitate reuse) may reduce the carbon footprint from a whole life cycle analysis perspective [13]. The consensus is that from the environmental point of view, steel reuse is a potentially excellent strategy [14], and general guidance about the reuse process is available [15]. Nonetheless, widespread reuse does not seem to occur.

1.1. Steel reuse potential in the UK

In the UK, steel reuse is a marginal practice, representing between 8 and 11 % of the steel arising from demolition [2, 16]. Other construction materials, notably bricks are commonly reused because they are valuable, for example Cambridge white bricks are not produced any more and are highly sought after for façades. However, the vast majority of emissions associated with construction come from cement and steel production. Almost all of the steel which is not reused is sold as scrap to be remelted. The carbon intensity of the electric arc furnace (EAF) route — 0.36 kg CO_2/kg steel — is much lower than that of the production of new steel in the UK. The latter is dominated by blast furnaces, with an average intensity of 1.78 kg CO_2/kg steel according to the *Steel Statistical Yearbook* [17] and the IEA [18].

This saving represents 7 % of the emissions from the UK steel industry, indicating constructional steel reuse could significantly participate in helping this industry reach its emissions reduction target, as defined in the COP21[19, 20]. To establish more precisely what are the potential savings, we estimated the amount of steel from sections arising from demolitions. The National Federation of Demolition Contractors (NFDC) represents 80 % of the market by value and has published in the last ten years a report indicating the total mass of metal in demolition arisings. Approximately 40 % of the total is taken by larger sections which could be reused, consistent with the work of Milford and colleagues [9]. We estimate thus that currently, between 40 and 80 % of the needs of the market could be covered by these arisings, a proportion which is set to increase (Figure 1).

Cooper and Gutowski wrote an extensive review of the qualities needed for a product to be most environmentally and economically suitable for reuse [21]. The products should be long-lived, substitute production — and thus not be the cause of more emis-

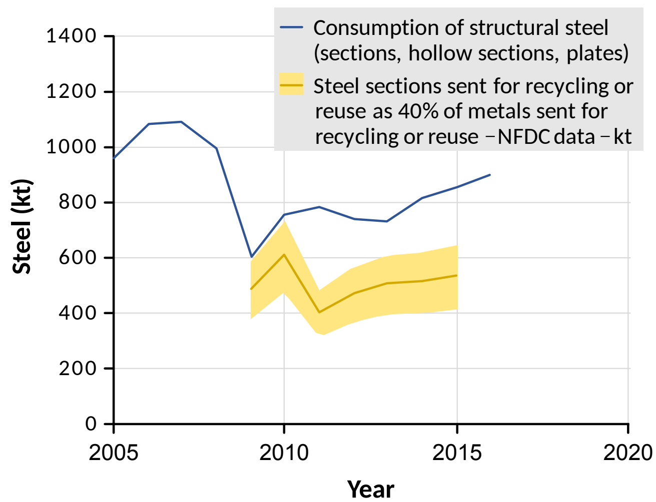

Figure 1: Mass of steel elements used in construction compared to an estimation of elements sent for recycling and reuse. The large uncertainty in the steel arising is represented by a band. This band assumes that the proportion of metal suitable for reuse lies between 30 and 50 %. Further, NFDC only represents 70 to 90 % of the demolition market by value. Taken together, these ranges define the uncertainty band.

sions through the rebound effect — and have high embodied carbon. All these properties are found in structural steel.

In conclusion, widespread reuse of construction steel would, in the UK context, significantly help the steel industry meet its emission targets.

1.2. Real and perceived barriers

Our study focuses on the UK design and build process only: construction practices are specific to each country as norms, industry structure and habits vary. Indeed, steel reuse in construction is a complex problem involving economic, sociological, technological, and legal considerations. In the UK, all actors of the construction supply chain experience specific barriers which deter them from steel reuse [22]. These barriers are summarised in the works of Vukotic [23] and that of Densley Tingley [4] among others. International comparisons indicate common challenges. For example, the work of Da Rocha [24] about steel reuse in Brazil attempts to cover all aspects. He identifies, in the Brazilian context, trust between actors about the quality of the steel to be a central problem. He further identifies logistical difficulties such as the quality of roads which may not be relevant to the UK. There is a body of work on practical experiences with steel reuse which analyses case studies, for example, Gorgolewski *et al.*'s collection of successful projects [25]. These show that when there is strong integration in the supply chain, for example when the firm responsible for the design of a new building is also the owner of the building it replaces, then steel reuse is found to be practical and cost effective. An important factor found in all studies is lack of trust between actors, which translates to onerous contracts, deterring many potential re-users. All these studies therefore indicate the key barrier to steel reuse is the articulation of the supply chain, which would need to be reconfigured to form a supply loop as per Geyer and Jackson [26].

Indeed, an important unresolved question in published studies is the lack of distinction between 'barriers to steel reuse' and 'barriers the interviewee has personally experienced'. This distinction is particularly important as the construction supply chain in the UK is strongly compartmentalised and the barriers any actor interviewed believes are important across the supply chain may not apply specifically to themselves, and therefore could be a perceived barrier rather than real. In the current study, we have tried not only to understand the barriers to steel reuse, but also how each actor would introduce steel reuse in their usual work-flow. To this purpose, we have held interviews across the supply chain, to piece together where the barriers arise and how they affect each part of the supply chain in practice. We have used an analysis method inspired from information retrieval to derive an index which measures the acuteness of the concerns of the actors we interviewed.

2. Methods

To establish how important each barrier to steel reuse is to each actor across the construction supply chain We set up an on-line survey and conducted interviews. A novel analysis of the answers is used to rank the perceived importance of barriers across the supply chain. Both interviews and survey were conducted concurrently, and the same questions were asked in both, although the interviews covered topics in more depth.

2.1. On-line survey and interviews

A structured online survey was set up. It comprised of a standard set of questions plus specific ones depending on the actor's role. The survey was available online from January to May 2016. It was advertised at a 'circular economy' events and a number of the interviewees also completed the survey. Invitations for filling the survey were distributed by leaflets, e-mail, phone, and in person. People who were invited to take part in the survey had various levels of experience with steel reuse, but all of them were interested in the topic.

Following the start of the survey, 30 actors were interviewed (Table of AppendixA). Most interviews occurred in person, although some were by phone and some information was obtained from follow-up emails. Interviews were conducted in Cambridge (Department of Engineering), London (offices of ASBP) or at the offices of the interviewees. The information gathered from 80 % of the interviews was verified by the interviewees who checked the post-interview reports. The interviews covered the themes of certification, cost, and programme. The interviewees all had an interest in steel reuse. We tried to reach representatives of all the members of the value chain, as well as a representative mix of experienced and inexperienced actors, and large, medium and small businesses.

The interviews alternated questions relating to the role each actor played in the supply chain in general (delays, costs, legal requirements) and specific questions about reuse steel, and how it fits (or would fit) in their work flow, to distinguish the barriers the interviewee had experienced, the barriers they felt prevented steel reuse in general, and the barriers they felt would prevent them from reusing steel.

We verified that the sample which, self-selected, nonetheless reflected the make-up of the construction in the UK. We compared the market share by value of companies classified according to the number of their employees to the share of interviews. The results of this comparison are shown on Figure 2. There is a fair match between the two distributions, indicating our interviews are likely to be representative of the overall attitudes to steel reuse in the supply chain. Importantly, the medium and large companies are well represented. We illustrate the similarity of the distributions by calculating the 95 % confidence interval of the UK's Office of National Statistics distribution over the last 6 years, assuming the percentages follow a log-normal law, and the implied precision of the distribution of the interviews as only discrete numbers of interviews can fall into each category. All 95 % confidence intervals overlap.

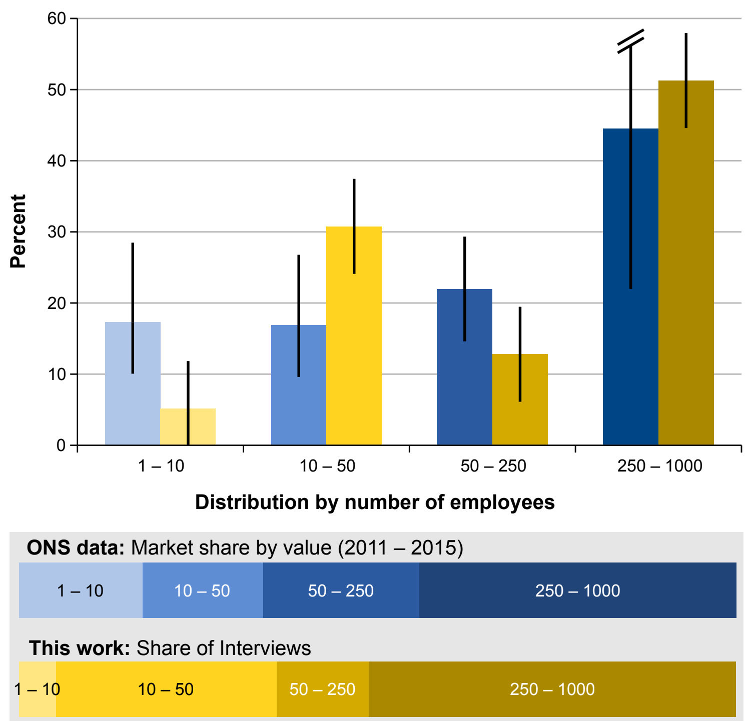

Figure 2: Share of interviews compared to market share by value of companies classified as a function of the number of their employees.

2.2. *Interview Methodology*

The questions used in the online survey were used as a guide for the interviews. After introducing ourselves and our project, we asked for permission to record the interview. Then, interviewees were encouraged to describe their normal operations as an introduction to the discussion, so that when discussing steel reuse they could contrast the different practices this could entail. The interviews then followed the same flow of question as the survey. Interviewees were free to go into details when answering questions.

All the factual data (such as prices and timings) were recorded and cross-checked with available sources from literature and other interviews. Anecdotes and specific concerns reported in more detail in the discussion section of this paper have been corroborated by multiple actors where possible, either from the same position of the supply chain or from actors with multiple roles.

Questions were asked in a neutral mode, and were open-ended, for example: 'How would you proceed if X happened?', 'What do you think about X?'. Nonetheless, since the same questions were asked during each interview, after recording the initial answer, we would follow-up with a question of the type 'In a previous interview, we heard X as an answer to the same question, what do you think about that?'. This allowed us to gauge the differences in perspective across different actors in the supply chain.

Finally, when the interviews were analysed, any concerns about barriers were aggregated under more generic headings. The aggregation was completed independently by both first authors, without coordination. The resulting classifications were almost identical, and the discrepancies were resolved after a short discussion.

2.3. Actors of the supply chain

For the purpose of the current work, we chose to divide the actors into six categories. These categories reflect roles in the design process rather than the organisation or specialisations of firms which frequently cover more than one aspect of construction. The figure 3 illustrates their relationships and the flows of steel in the common case of construction, and when steel is reused.

Architects & Clients have distinct roles specifying the parameters for buildings. For the purpose of this study, we have grouped them as a single category as they share the same concerns.

Structural engineers are responsible for specifying the dimensions and the steel grade of the beams and columns, and are responsible for the overall structural soundness of the building design.

Main contractors coordinate and organise all the subcontractors responsible for the fabrication, erection and other operations required to complete the construction of buildings. In large projects, they may sub-contract architects on behalf of the clients. In the latter case, their involvement and influence occurs earlier in a project than otherwise.

Fabricators are responsible for the procurement, fabrication and erection of the elements designed by the structural engineers. Furthermore, they are responsible for the design of the connections between the elements of steel structures.

Stockists serve as a broker between the mills or international distributors and the fabricators. They provide the sections or plates the fabricators need.

Demolition contractors are responsible for clearing the terrain at the end of the life of a building. They can demolish the building or deconstruct it depending on time, money or other constraints. Demolition contractors commonly sell on the materials they salvage from the buildings they work with.

The construction of a building also requires the work of a number of other subcontractors, in particular those responsible for the heat and ventilation system, plumbing, *etc.* As they are not affected by the use or reuse structural steel, they have not been considered in this study.

2.4. Barrier and actor perceived importance

The interview approach anticipated some barriers would be actor-specific and some would be faced by all actors. To quantify which barriers are most prominent for each

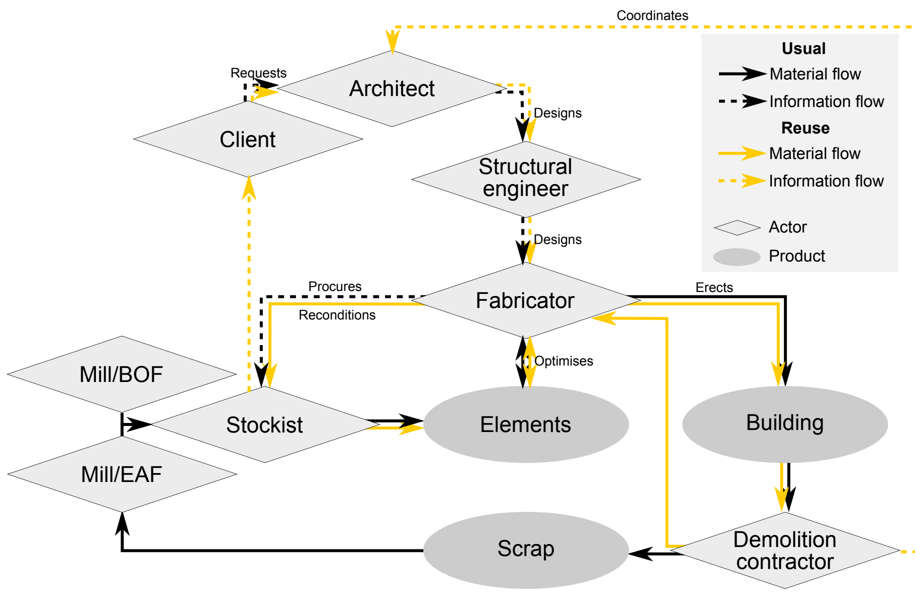

Figure 3: Flow of information and steel in the construction value chain. the central role of the fabricators and stockists is apparent.

actor, an index was computed. This index is inspired by information retrieval methods used in natural language processing [27]. We follow the same naming convention as in this field: tf stands for ‘term frequency’, and idf ‘inverse document frequency’. In this analysis, ‘terms’ are the barriers, and ‘documents’ are the mention of barriers taken from the interviews. In a subsequent analysis, ‘terms’ are actors, and ‘documents’ are the interviews grouped by barriers. This perceived importance measure serves to distinguish important non-specific barriers, such as costs which affects all actors, from important actor-specific barriers. Since the barriers themselves have been grouped into broad categories, it is well understood that under a single header, *e.g.* cost, each actor experiences the barrier quite differently. The measure does not give information on how easy the barrier is to be overcome, or how important it is, but instead how important the barrier is to each actor *compared to other actors*.

Calculating this index is done in two stages. The inverse of the frequency of mention of each barrier is an index of how uncommon they are. For example, cost is mentioned by all actors but old/new perception mainly concern stockists, therefore cost has a low index value and old/new perception consideration has a high index. With N the total number of respondents and n_b the number of mentions of barrier b

$$\text{idf}_b = \frac{N}{n_b} \tag{1}$$

However, a mention by only few respondents/interviewees within an actor group may indicate that a particular barrier only affects this respondent or interviewee personally but is not representative of this actor group. Therefore, the frequency of mentions within a group g is an index of how important a barrier is for this group.

$$\text{tf}_g = \frac{n_g}{N_g} \tag{2}$$

To provide a combined measure of the importance of barriers for each group compared to all others, the two indices are multiplied.

$$\text{tf-idf}_{bg} = \frac{n_g}{N_g}\frac{N}{n_b} \tag{3}$$

This provides a score of the relative importance of barriers for each actor group. The higher the score, the more important the barrier is for an actor compared to the same barrier for other groups. The overall mention frequency of any barrier remains a measure of its absolute importance. Nonetheless, the *presence* of salient barriers indicates actors face more immediate challenges due to a specific barrier.

A lower score therefore does not mean that a barrier is not important, but that it is not important to a specific actor. The same analysis was performed looking at the mention of actors per barriers. This second analysis gives an indication of which actor suffers the most from barriers.

2.5. *Distinction between perception and reality*

To distinguish between real and perceived barriers, we used two strategies. During the interviews, we were able to distinguish whether a barrier was experienced personally by the interviewee, or whether they were describing a barrier generally or for some other actor. The second strategy was to contrast the discrepancy between the generic estimation of the difficulty of steel reuse with the difficulty actually experienced by the same actors in their projects.

These strategies distinguish between real and perceived barriers grouped under the broad categories which we described. However, a wealth of details were given by the actors concerning projects in which they participated in; these are described in more detail in the result section of the paper. These concern specific difficulties which were encountered, each of which can be considered in its own right ‘a barrier’, and all of which are ‘real’.

3. Results

The 24 survey respondents came from a mix of small to large firms. Almost half companies employed more than 250 people (Figure 2). As the respondents are self-selected, this may reflect the breadth of interest towards steel reuse across the construction industry.

3.1. *Experience of steel reuse in the sample*

More than 80 % of all respondents had heard about reusing structure steel before the survey and almost 60 % had experience of reusing structural steel elements (Figure 4).

The largest group of respondents played a role in the deconstruction of a building and the reclamation of steel (16 %). A smaller group was responsible for specifying second hand steel in a project as an architect or engineer (12,5 %) and steel fabrication (12.5 %). The smallest group was firms which requested reused steel in a project (as a client) or supplied reclaimed structure steel for a new project, both the 8.3 %. One third of respondents had participated in between two and five projects using second hand steel. One eighth of respondents had participated in more than 10 projects.

The tonnage of second hand steel used in the respondents' latest projects was generally high or very high. 16 % of respondents reported having used between 10 and 200 t of second hand steel in their latest project. One eighth of respondents used below 10 t of reused steel.

3.2. Identified barriers

To analyse the barriers across the supply chain, we have grouped them under broad categories, which reflect areas of concerns all actors share. There barriers were chosen based on the the interviews and the survey. They also reflect previous work on the topic such as the papers by Vukotik [23] and by Densley Tingley [4]. The barriers we have studied are:

1. **Profit opportunity/cost**. This barrier both concerns the cost of reusing steel, and the risks associated with changing business practices
2. **Programme**. The construction of a building requires many different specialists to work together in an elaborate sequence. Any disruption in the procurement can cause significant delays and cost overruns. Establishing a reliable schedule when there is a change from the common practice is always difficult.
3. **Quality/certification/traceability**. The construction industry, in particular the fabricators, have seen their practices changed with the introduction of CE marking, which guaranties the properties of the steel. As this mark is normally delivered through the production process at the mill, there are some questions as to whether it can be applied to reused steel. This in turn can increase the cost of insuring constructions.
4. **Availability/Dimensions**. The structural design process normally assumes that the elements will be fabricated as required. However, when designing with reused elements, the desired sizes or lengths of elements may not be available and

substantial changes to plans may be required, incurring costs and delays. These barriers were grouped together because they address the same concern (whether the steel can be procured) but are expressed differently by different actors.

5. **Old/New perception**. Many participants in our interviews worried that their clients would feel that old steel is 'inferior', and therefore refuse it or demand a discount.

6. **Trust/Lack of communication**. The design, procurement, fabrication and construction of building follows well established patterns. Other members of the supply chains are not always trusted to be able to surmount new challenges. Liability and insurance issues also fall under this category. This concerns also the questions related to the professional insurance (PI). These were mentioned in the interviews but nearly always as 'somebody else's problem', *e.g.*, 'This other actor will not do thing *x* because it would not be covered by their PI'.

7. **Uncommon practice**. Changes in the usual way of doing things may not be possible without investments or legal advice.

8. **Design for deconstruction**. Demolition contractors face significant challenges in recovering the steel of buildings when the design did not account for this possibility. For engineers, this is a supplementary design constraint which is difficult to price.

Programme and cost are important barriers for all actors: very few actor will consider reused steel if it costs more or if it takes more time. However, an advantage in one of these aspects can compensate a disadvantage in the other. For example, some delays can be tolerated if the costs are lowered, or on the contrary, one may decide to pay more to speed up the programme.

3.3. Barrier ranking

First, the overall importance of barriers was established by computing the frequency of mentions across the whole supply chain in the interviews and the survey. The results are reported on Table 1.

Table 1: Ranking of barriers in the interviews and survey. Not all barriers were mentioned in the internet survey. The similar scores indicate that the survey and interviews are consistent.

Rank	Frequency		Barrier	
	S	I	Survey	Interviews
1	0.71	0.67	Availability/Dimensions	Availability/Dimensions
2	0.67	0.67	Quality/certification/traceability	Quality/certification/traceability
3	0.58	0.63	Profit opportunity/cost	Profit opportunity/cost
4	0.50	0.60	Programme	Trust/Lack of communication
5	0.46	0.53	Trust/Lack of communication	Programme
6	0.38	0.47	Uncommon practice	Uncommon practice
7	0.21	0.23	Old/New Perception	Old/New Perception
8	—	0.17	Design for deconstruction	Design for deconstruction

Both the interviews and the survey mentions of barriers were used to calculate a single global idf. The consistency between the frequency of barrier mentions in the survey and in the interviews gives confidence that these two sets of answers can be used together for this purpose. Design for deconstruction was not mentioned in the survey, however, and the assumed frequency for the purpose of computing the idf was 0.17 the interviews (Table 2).

Table 2: idf values for the barriers. These were computed using the weighted average of the frequencies.

idf	Barrier
1.46	Availability/Dimensions
1.50	Quality/certification/traceability
1.64	Profit opportunity/cost
1.86	Trust/Lack of communication
1.93	Programme
2.35	Uncommon practice
4.50	Old/New Perception
6.00	Design for deconstruction

The online survey provides an overview of motivations for steel reuse and barriers, real and perceived. The first motivation for reusing steel in the respondents' latest projects was a request by the architect/designer (16 %). Costs savings and requests by the client were mentioned respectively by 12.5 % and 8.3 %. One respondent (4.2 %) noted that the motivation was by the contractor's request. A large group, 16 % as a motivation answered 'other', which included steel reclamation in purpose of selling as a new steel or as a material to recycling. None of respondents answered that they were motivated by reducing carbon emissions, despite almost 85 % of respondent's companies having a policy in place dealing with environmental impacts.

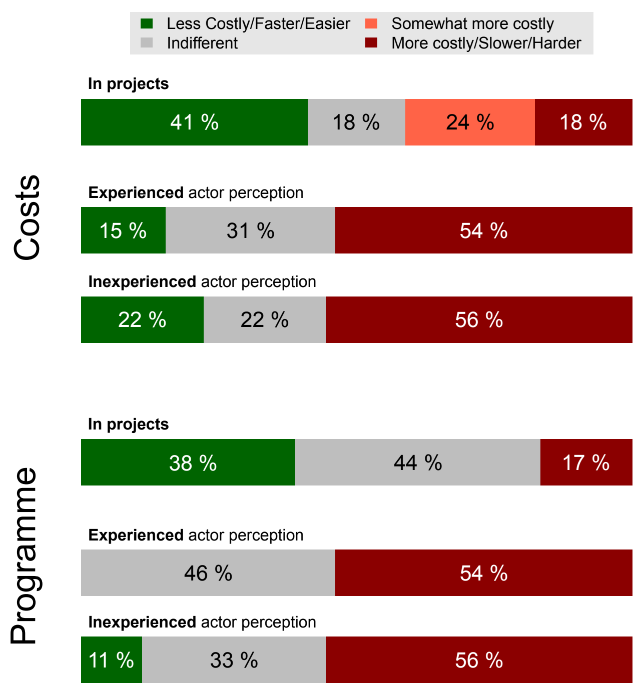

Figure 4: Difference in responses in the web survey between respondents with and without experience with steel reuse. The expectation of actors having experience with steel reuse contrasts with their assessment of their latest projects

There is considerable scepticism concerning the impact of reused steel on costs and programme (Figure 4). Almost 60 % of respondents expect reusing steel to lengthen programmes, while 40 % expect no impact. No respondents expected shorter programming. More than a half of respondents expect reusing steel to be more expensive *versus* 30 % expecting similar costs. Only 17 % expect a lowering of costs. This is in contrast to actual experience, where one third of the respondents when describing their projects involving reused steel said that it was easy to reuse steel, 16 % noted that it was similar and only 8 % believe it was difficult in comparison with the new steel. For respondents who used reclaimed steel, one third noted cost savings using second hand steel. The same number of respondents were not sure if there was a cost saving. One sixth of respondents noted no change of costs using second hand steel and the same number of respondents noted that costs increased.

The perception that reusing steel is difficult does not align with the real experience of the respondents which is positive for specific projects. We believe that although specific projects are easy or fast or cheap, the belief generally held is that reusing steel is difficult *in the abstract*. It is likely that the respondents answered not according to their personal experience, but gave answers which reflected the overall scepticism over steel reuse across the supply chain.

The considerable difference between the perception of barriers and the experienced barriers indicates a lack of communication across the supply chain. The question on the survey may have been interpreted as: 'what are the barriers to steel reuse', which is distinctly different from 'what barriers have you experienced in steel reuse'. A further indication of this is the relative lack of any barrier having a much higher perceived importance than any other (Figure 5).

To identify the specific barriers actors experience across the supply chain, we analysed the in-depth interviews following the same methodology as the survey.

3.4. Interviews

We have scored the barriers mentioned by the actors during the interviews. The results are reported on Figure 6. Further, we have grouped together the barriers mentioned which concerned other actors: put together, these present a picture of the perceived

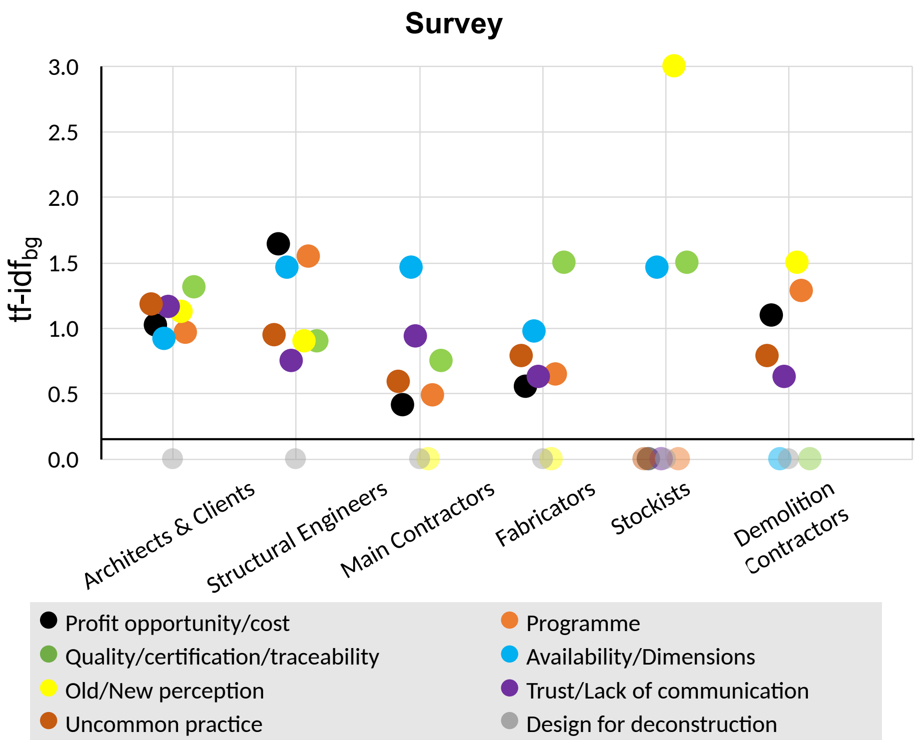

Figure 5: Perceived importance analysis of the barriers to steel reuse from the online survey. The higher the perceived importance score, the most pressing a barrier is for the concerned actor. Higher scores in general can be understood as a measure of how critical the barriers faced by an actor are. The survey results do not indicate that any barrier is particularly important.

barriers to steel reuse.

The perceived importance of the of barriers, *i.e.* the relative importance for a specific actor, is higher for the demolition contractors, stockists and fabricators. Indeed, during interviews, specific obstacles were described and scenarios discussed with these actors, whereas other actors had more general observations. This is also consistent with reports of failed steel reuse projects where steel reused had to be abandoned as a option because the *e.g.* the fabricator could not or would not accept the steel procured from yards.

A barrier which is high for fabricators and demolition contractors is 'uncommon practice'. This does not indicate that steel reuse is difficult because they have no experience with it, but that large changes in their processes would be required. Indeed,

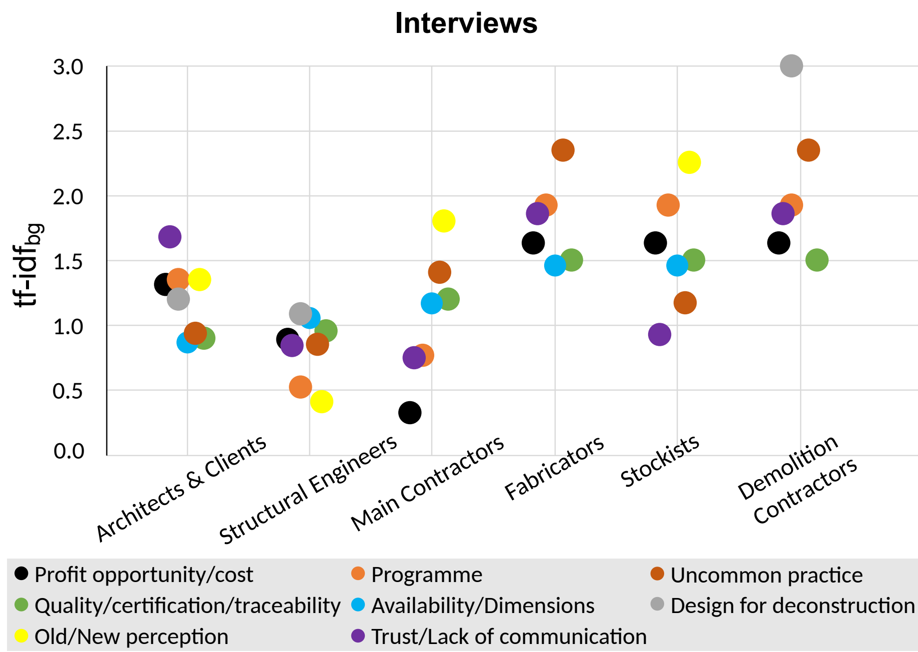

Figure 6: Perceived importance analysis of the barriers to steel reuse from the interviews. The higher the importance score, the most pressing a barrier is for the concerned actor. Higher scores in general can be understood as a measure of how critical the barriers faced by an actor are.

as we found out in the interviews, fabricators need to tie significantly more of their production capacity to projects reusing steel than ‘normal’ projects, and stockists have a business model which does not allow for the long-term storage of steel. For demolition contractors, this also translates as the lack of a reliable market for reused steel.

’Financial concerns’, although lower in perceived importance than ’uncommon practice’ are nonetheless higher than in the rest of the supply chain. These barriers cannot in general be very salient as they are felt by all actors, but a relatively higher score indicates that they represent core concerns. However, architects, main contractors and structural engineers are protected by the ‘cost-plus’ structure of projects, and would simply charge higher costs to the clients.

Finally, the profit opportunity barrier faced by demolition contractors is somewhat different than for stockists and fabricators: demolition contractors can benefit from deconstruction as they frequently retain the right to sell on salvaged materials. However, there is a concern that there is no substantial market for reused steel and that it can only be sold for scrap.

An alternative view of the same results is the perceived importance of *actors* (Figure 7). This view highlights the particular importance of the fabricators, stockists and demolition contractors, particularly visible from the interview analysis. The result from the survey analysis is explained by the number of responses left blank by these actors. During the interviews, we found that this was because in many instances, respondents in these roles felt the questions were too generic to properly convey the barriers experienced.

A key observation from the online survey was that similar answers were given by all actors of the supply chain. We interpret this as the perception of barriers being shared across the supply chain, despite every actor facing distinct barriers. The difference between interviews and survey may come from the fact the interviews reflected more actual experience, whereas the survey is a reflection of perceptions. Nonetheless, the perceived importance of barriers as computed from the results of the interviews and the survey both show higher values for the fabricators, stockists and demolition contractors.

4. Discussion

Barriers to steel reuse are well described in a number of previous works [23, 4, 25, 22, 24], and seem to differ somewhat depending on the country which is the focus of any particular study. The actors interviewed in this study all work in the United Kingdom. Although many barriers in the following are discussed, no actor of the supply chain, from the clients to the demolition contractor, will favour steel reuse if it causes costs or delays.

4.1. Perceived and real barriers to steel reuse across the supply chain

The top-2 barrier per actor and score are found in Table 3. We describe below the barriers each actor experiences, and link these to their ID in the table of AppendixA in

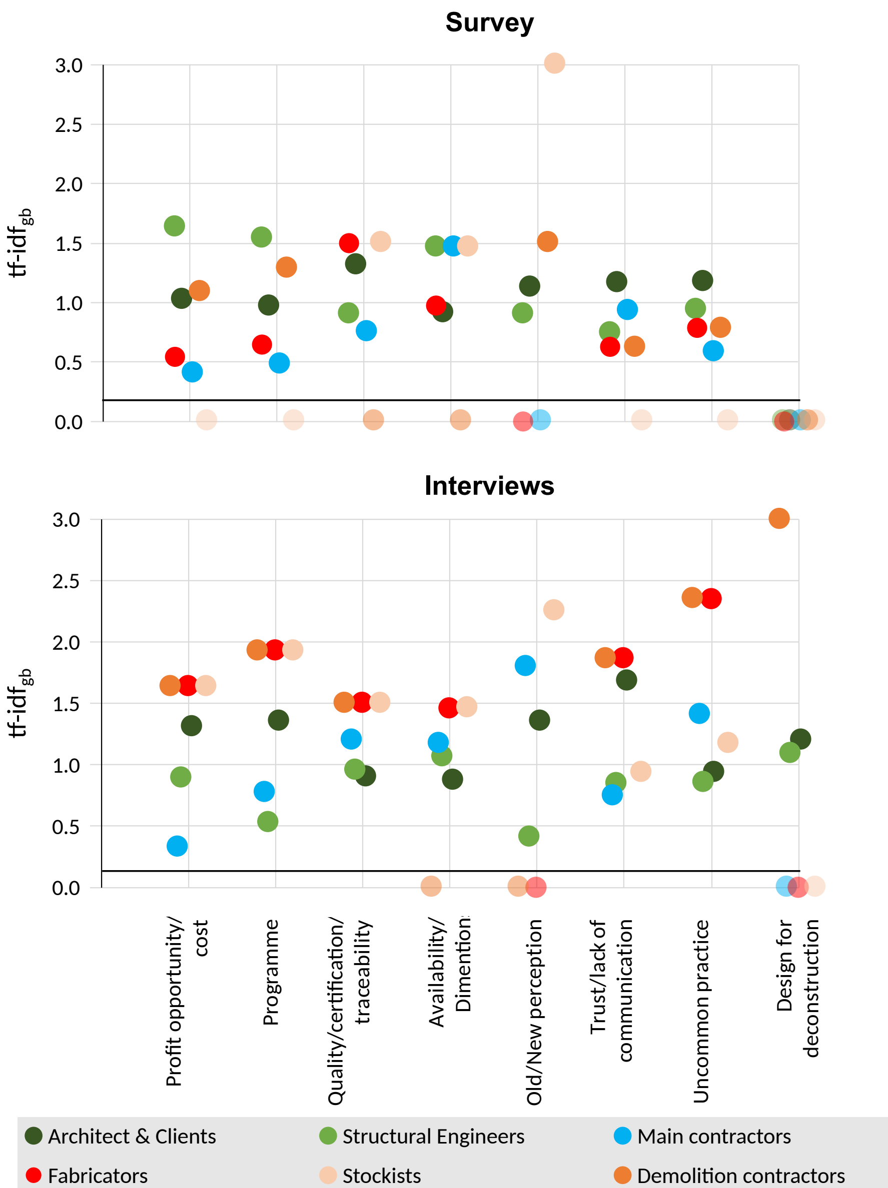

Figure 7: Perceived importance of barriers ranked by actors. The comparison shows the interviews highlighted the particular importance of the fabricators, stockists and demolition contractors.

395 brackets. These can are contrasted with the barriers perceived to be most prominent.

396 **Architectural designers, clients** The two main barriers perceived by architects to be

Table 3: Top two barrier for each actor. The tf-idf score from the interviews is also given.

Actor	Top barrier	Second barrier
Architects and clients	Trust/Lack of communication 1.40	Old/New perception 1.25
Structural Engineer	Design for deconstruction 1.35	availability/dimensions 1.15
Main contractors	Availability/Dimensions 1.26	Uncommon practice 1.04
Fabricators	Quality/certification/traceability 1.46	Uncommon practice 1.17
Stockists	Old/New Perception 4.51	Quality/certification/traceability 1.46
Demolition Contractors	Design for deconstruction 2.70	Programme 1.45

obstacles to steel reuse are trust and the perception that old steel is inferior.

The architects interviewed were interested in the organisation of space and the æsthetic aspects of construction (this fact was mentioned in interviews A1 and A2 as per the table of AppendixA). Although they have an interest in being ecologically friendly, they will **only design within the budget set by the client**. Large clients can have an interest in lowering their carbon footprint as part as a prestige strategy and there is general goodwill towards environmentally friendly practices (C1, C2, C3, C4, AD1, AD2, AD3, AD4). Nonetheless, investment towards 'green' outcomes happens if there is visibility or a heritage motivation. This motivation to preserve heritage (mandated in the case of listed buildings) drove the design of projects we were told about (M1). However even considerable effort, financial and technical, may not yield environmental benefits: many reused elements only serve a decorative purpose (C1). **Clients are not usually ready to accept delays**. For example, a project for new student residential buildings for the University of East Anglia was also seen as a potential re-user of steel. However, due to the programme timing there was no time to assess the steel, and the option was dropped (S1).

Main contractors The two main barriers perceived as preventing steel reuse are, for main contractors, Availability and the fact that reuse is uncommon.

Main contractors are responsible for the overall management of projects. They can set benchmarks: for example a large main contractor has an internal policy of calculating the carbon footprint of all their projects (M3). Nonetheless, their role becomes prominent only when most of the key decisions about the project have already been made, and although they have some influence, the changes they can drive are marginal. Therefore, their concerns about steel reuse are mostly about certification. Their role as a manager of legal liabilities can push them to block reuse, unless a solution to certify the steel is found.

BREEAM credits are the main driver to changes main contractors can drive. However, the credits for steel reuse are marginal, and in general not cost effective: for example, to get the credit on material reuse, it is much easier to use recycled concrete aggregates (a common occurrence according to interviews) than to try and procure reused steel.

In certain projects, the main contractor is also the client (C3, M4) or has a deep understanding of engineering. In these cases, we found that steel reuse can happen successfully. For example, a building was relocated 2 km from its original location. As the developer in this case was also an engineering firm, the risks and benefits from the operation were well understood by all parties. In this instance, substantial cost savings ($\approx$ 25%) were achieved, and achieved an estimated 56 % of the embodied carbon compared to a new building.

Currently, specifications are written in an *ad hoc* fashion and tend to overburden the fabricators with **risks and liabilities** (M2). Engineers do not in general have the power to write non-standard specifications. Therefore, it would probably be helpful to define a standard for the certification of reused steel (S4). The new engineering building of Cambridge University, opened in July 2016, had a client which specifically asked for reuse. However, the difficulties in procurement and legal obstacles prevented this objective from being achieved (M2); it was not possible to obtain insurance for the reused elements.

Structural engineers The two main barriers perceived by engineers to prevent steel reuse are that buildings are not designed for deconstruction and beams may not be available in the required dimensions.

Engineers guarantee the soundness of designs. This is built upon the premise of **certified elements** and well-executed fabrication and erection. It is simpler and more cost-effective to rely on standard specifications, such as CE marked steel of known grades than to specify the specific strength and properties the elements should have. This is not a difficult problem for the structural engineers reflects the operation of some engineering firms. Most engineers we talked to told us they would have no problems signing under a design, provided they knew the steel had the required properties (S1, S4).

Structural engineers are frequently **pressed for time**. A common remark was that 'they could do a better job if they had more time' (S1, S4). There is a feeling that in the name of saving money upfront, there is less value for money created in the design. In this context, most engineers think it would not be acceptable to revise the designs if the specified beams could not be procured from reused steel. Nonetheless, we found no example of design originating from a set of already-procured reused beams having happened, except as theoretical exercises in literature. Rather, successful reuse cases frequently involve updates to the design late in the process.

We interviewed (S3), an engineer in charge of the successful BedZED project [28]. In this experience, the design and procurement happened concurrently, but only minor alterations were required to make use of recovered elements. Importantly, he says there was no great difficulty to find steel matching the requirements. However, this is at odds with the description of other engineers we interviewed, working for larger firms (S1, S4, C2). There, procurement is handled by a different team than the design group. To introduce a list of elements at the beginning of the design process as a supplementary constraint which would be a break in current practice.

Overall, structural engineers look favourably to reusing steel. They take pride in their jobs and enjoy an interesting challenge. Provided they are given the time they need to do the design, they see no problem with using reused steel instead of new elements (S1, S2, S3, S4, S6, S12, S13). Once the engineers have specified the elements, the design is passed on to the fabricators.

Fabricators The two main barriers perceived by Fabricators to prevent steel reuse are the lack of certification of steel, and the fact that the practice is uncommon.

They are responsible for the realisation of the frame design and its erection, and also design the connections (SF1). In larger projects, they will rationalise and optimise the structural design. Fabricators are key to successful reuse: for example, a project to reuse steel in the construction of a college in Newcastle failed due to fabricators refusing to work with reused steel after it was delivered to the factory (S3). Two barriers in particular dominate for the fabricators: certification of the steel and time required to fabricate the elements (M4, C3).

The first barrier, **certification**, follows the roll-out of CE marking in the industry. We were told that this had significantly changed the way operations were conducted: all welds are now systematically inspected as a standard industry practice, and there is a much greater attention given to the training of the workers (SF1, SF2, ST2). The change was welcomed as it is seen as a validation of the high quality of the work. Nonetheless, this may cause problem for reused steel: any practice must fit within the specification, and there is a greater demand for certainty. In general, the way steel elements are specified can cause problems even in the case of new steel: some design firms specify whether elements should be hot or cold rolled — even in beams which do not require such specification (SF1); then either the specification must be amended or there will be a large cost for the procurement of the element.

The second barrier for fabricators is **the pressure of time**. Designs must be quickly produced: fabricators fear they may not be given the time to adapt to the specific demands of reused steel. The time pressure also conditions the fabrication process: reused steel should be 'as new' to be processed (SF1). Preparing the steel for fabrication may tie up production lines which would otherwise be used to fulfil other contracts. Reused steel elements are all different in general, and can have any combination of holes, stiffeners, welds, end-plates, *etc.* preparing a reused steel element for fabrication is a different operation each time. This is costly because the re-tooling/moving required for each new clean-up operation is the most time-consuming operation in the workshop. Paint can be a particular problem. Although reused elements can have perfectly serviceable intumescent paint already applied, it has be removed and the elements re-painted to match the new specifications. This can be particularly difficult if a very high quality finish had been chosen in the previous use (SF1).

Stockists The two main barriers perceived by Stockists as preventing steel reuse are the perception that old steel is inferior to new and the lack of traceability of the steel.

Stockists provide steel elements to the fabricator for fabrication and erection. They act as the intermediaries between the steel mills and the rest of the supply chain and aim to deliver simple and smooth procurement. Larger sites turnover their stocks in 48 hours, measured from the arrival of a beam to the yard to it being sent to a client, and maintain up-to-date lists of the most in-demand elements (ST2). One of the stockists we talked to also offers as a service to buy from other stockists or mills surplus and ”downgrade” elements from offshore (ST1).

Reused steel requires long storage times. In turn, an effective operation requires the availability of large storage space, and cheap access to land. We were told that in the south of England, this was not economically viable. Indeed, ST1 are based in North Yorkshire and has large storage areas. ST1 commonly hold elements for years, waiting to make a profit when the price is right. Further, as the turnaround time in the normal operation of stockists is short, a reuse branch in their business would not add much value and incur large costs (ST2).

Stockists sell steel which is CE marked, as part of the steel making and rolling process. **The standardised certification process** has allowed procurement of the elements from a larger number of sources, although the quality of the steel from 'China' — as well as the validity of the certificates — was said to be a concern (ST2). In general, traceability is a key part of the stockist's normal business model. It is on this foundation that the steel can then be certified, fabricated and erected. ST1, a reuse specialist, tests every single element and provides a certificate with all the properties of the steel since it cannot guarantee the traceability of the steel. This certificate, although it provides identical information as the CE certificate, is non-standard. There is therefore a concern that it might not be allowed in the future if the rules on CE marking are tightened.

Demolition contractors The two main barriers perceived by Demolition contractors as preventing steel reuse are that buildings are not designed to be deconstructed and the lack of time.

Demolition contractors determine the availability of reused elements as they make the decision whether to demolish the building and sell the steel as scrap or deconstruct the building while extracting the steel for potential reuse. Therefore, a market for steel reuse can only exist if they find more value in selling reused elements to stockists than for selling scrap. The main markets for reused steel, in the experience of the demolition contractors we interviewed, are the agricultural and temporary structures market, as these have no requirement for CE marking (D1).

Works in cities may force them demolition contractors to deconstruct rather than demolish due to the necessity of reducing noise and dust, but this opportunity for reuse is usually ignored: the elements were still sold for scrap (D1). Although buildings are frequently left unoccupied for long periods of time before their decommissioning, **this time is rarely used for pre-demolition audits** (D1). Such audits, as recommended by the national federation of demolition contractors (NFDC), would assess what elements are available but also give time to find a buyer. These audits would however not have this as a primary purpose: the main concern of demolition contractors starting a job is health and safety.

Demolition contractors **rarely own large stockyards and cannot hold large amounts of steel**. It is therefore necessary for them not only to find a buyer for the materials reclaimed, but to find the buyer or storage site before they start a job. Selling the steel for scrap is possible without the need for storage. Nonetheless, when the price of scrap is very low, the profit margin is reduced and there is an incentive to try and find other ways to capitalise on reclaimed steel such as reuse. Demolition contractors look for any opportunity to profit from reclaimed material (D1, D2, D3).

The **concerns about steel certification** from the other members of the supply chain are a central issue for the demolition contractors: they would need the steel to be fully traceable or certified to be able to sell it on for anything other than agricultural structures. We were told that ideally, every beam would be marked and have a verified certificate. In theory, there would be a repository of all the elements with their history and properties. Such a repository would help traceability and thus reuse, however there was much skepticism about BIM models being available to the building end of life to facilitate reuse.

Demolition contractors in the past used to reclaim much more material from their jobs. However, greater mechanisation on one hand, and changes in the building practices on the other have changed this. We were told that the change also came with much better health and safety for the workers, and therefore that there was **little appetite for a return to the more labour-intensive practices** of the 60s and 70s (D1).

4.2. A possible solution — better communication across the supply chain

Successful steel reuse projects are generally the result of a willing client and a tightly integrated team [25] responsible both for the design and rebuilding. This can take a number of forms:

- The owner of the new building also owned the previous building (or has a relationship with the owner). In this case, as a source of elements is identified at the onset of the project, the odds of reuse are increased,
- the main contractor is also the designer. In this case, much of the legal uncertainty is eliminated. A higher level of trust between the teams responsible for the design and construction encourage successful reuse,
- the owner of the old and new buildings is also responsible for the design or fabrication. Prestige can be derived from an ecologically-friendly construction and serve as advertising for the company.

In all these cases, the supply chain is simpler and more aggregated compared to standard construction projects. Thus, when an opportunity for reuse is identified, their are fewer obstacles to forming a practical plan.

In contrast, if only a single actor in a supply chain is unwilling to reused steel, the project will not go ahead. Building trust requires time. If the actors coming together on a project have never worked as a team before, they will rely on common practice and industry norms more heavily. Steel reuse becomes then unlikely, as it is not addressed in the norms.

To help overcome this communication barrier, it would be helpful if the fabricators, who face the most salient barriers, were involved in project design from the start. Thus, they would have more time to prepare for the uncommon operations involved in reuse, and they would feel more involved in the project. A higher level of 'buy-in' reduces the risk of blocks. As a supplementary benefit, better guidance on the cost of some element design choices can yield better, cheaper designs.

The certification barrier can most likely be solved in larger projects by the main contractor. For smaller projects, similarly to the recommended practice of involving fabricators early in the design process, reused steel stockists should take on the responsibility of certifying the steel and work early on with the fabricators and design engineers to find a suitable specifications which do not prevent steel reuse in practice.

5. Conclusion

A detailed reconstruction of the construction industry cross-supply-chain barriers associated to steel reuse in the UK showed that it is a difficult proposition. However, the contrast between the negative view of steel reuse in the surveys and interviews contrasts with the more nuanced view from actual experience. This may indicate that some of the barriers are only perceived. The analysis of the perceived importance of barriers supports this analysis, but shows that some actors face stiffer challenges than other.

Some of the negative perception seem to originate in the lack of communication across the supply chain, leading to onerous contracts, delays, and costs, all of which could be avoided through better coordination.

We found that to allow for a market for reused elements to take off a number of steps should be taken:

1. Stockists and fabricators should work together so that reused steel elements are indistinguishable from new steel elements when they reach the fabrication stage.

2. Capital investments are necessary for stockists to be able to manage large stocks of reused steel and condition it for fabrication.

3. The volume of elements potentially available for reuse can cover large proportions of the overall market. However, due to a lack of transparency and programme constraints, nearly all the steel is currently melted as scrap, even when buildings are deconstructed. Complete plans of structures should be kept so that a precise inventory can be made before demolition.

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AppendixA. Summary of actors surveyed

Table A1: Summary table of all actors interviewed and surveyed. The ID is the anonymised reference to the actor used throughout the text.

Actor	ID	Experience with reuse	Company size	Survey date	Interview date
Architects & Clients	A1	no	0-10	23/02/2016	23/02/2016
	A2	yes	10-50	05/05/2016	24/02/2016
	C1	yes	250-1000	01/03/2016	24/02/2016
	C2	no	50-250	03/02/2016	24/02/2016
	C3	yes	250-1000	—	19/01/2015
	C4	yes	250-1000	—	24/02/2016
	C5	yes	250-1000	22/01/2016	—
	C6	yes	250-1000	16/02/2016	—
	AD1	yes	1000-5000	—	25/02/2016
	AD2	no	250-1000	30/03/2016	03/03/2016
	AD3	yes	250-1000	—	29/01/2016
	AD4	yes	1000-5000	—	24/02/2016
	AD5	yes	10-50	22/01/2016	—
Structural Engineers	S1	yes	250-1000	22/02/2016	22/02/2016
	S2	yes	10-50	02/02/2016	23/02/2016
	S3	yes	10-50	16/03/2016	25/02/2016
	S4	yes	50-250	—	22/03/2016
	S5	yes	50-250	—	12/02/2016
	S6	no	250-1000	—	25/01/2016
	S7	no	10-50	—	25/01/2016
	S8	no	10-50	—	25/01/2016
	S9	yes	10-50	—	25/01/2016
	S10	yes	1000-5000	—	26/01/2016
	S11	yes	250-1000	—	29/02/2016
	S12	no	0-10	23/02/2016	—
	S13	not sure	250-1000	07/03/2016	—
Main Contractors	M1	yes	10-50	—	05/02/2016
	M2	not sure	250-1000	02/02/2016	16/02/2016
	M3	no	250-1000	—	02/03/2016
	M4	yes	250-1000	—	24/02/2016
	M5	yes	50-250	04/02/2016	22/02/2016
	M6	no	250-1000	16/02/2016	—
	M7	not sure	250-1000	18/02/2016	—
Fabricators	SF1	no	10-50	05/05/2016	18/03/2016
	SF2	yes	250-1000	24/01/2016	—
	SF3	yes	250-1000	17/02/2016	—
Stockists	ST1	yes	10-50	29/02/2016	18/01/2016
	ST2	no	10-50	—	15/04/2016
Demolition Contractors	D1	yes	10-50	05/05/2016	05/04/2016
	D2	yes	10-50	08/02/2016	—
	D3	yes	10-50	05/02/2016	—

AppendixB. Questions used in the on-line survey

Table A2: Reuse of Structural Steel — Survey questions.

No.	Question	Choice
		A. Preliminary questions
1	What type of company do you work for?	a) Architectural / Structural design b) Steelwork contractor c) Main contractor d) Demolition / Deconstruction e) Steel supplier / stockholder f) Client g) Other (please specify)
2	How many people are employed in your company?	a) 0-10 b) 10-50 c) 50-250 d) 250-1000
3	Does your company have a policy in place dealing with environmental impacts?	a) Yes — If Yes, could you give details? b) No c) Not sure
		B. Experience with steel reuse
4	Had you heard about the idea of reusing structure steel, before this survey?	a) Yes b) No
5	Does your company have experience of reusing structural steel elements?	a) Yes b) No — if No, jump to question 19 c) Not sure — if Not sure, jump to question 19

Table A2: Reuse of Structural Steel — Survey questions.

No.	Question	Choice
6	What part did your company play in the process of reusing steel?	a) Requesting reused steel in a project (as a client) b) Specifying reused steel in a project (as an architect or designer) whether or not the project was realized c) Fabricating a structure using reused steel d) Supplying reclaimed structural steel for a new project e) Deconstruction and relocation of a building to a new site f) Deconstruction of a building and the reclamation of steel elements
7	How many projects with steel reuse have you participated in?	a) 1 b) 2–5 c) 5–10 d) more than 10
8	What was the motivation for reusing steel in your latest project?	a) Requested by the client b) Requested by the architect or designer c) Requested by the contractor d) Cost saving over new steel e) Carbon emissions reduction f) Other (please specify)

Table A2: Reuse of Structural Steel — Survey questions.

No.	Question	Choice
9	What tonnage of reuse steel was used in your latest project? — Could you specify?	a) 0 to 10 b) 10–100 c) 100–200 d) more
10	Did the reuse of steel result in cost savings or increases for your latest project? — If possible, please provide details.	a) Savings b) Increases c) Indifferent d) Not sure
11	Was the environmental benefit of reusing steel quantified in your latest project?	If possible, please provide details.
12	How easy was it to reuse steel in your latest project? — Please list the main difficulties encountered.	a) Easy b) Similar to new steel c) Difficult
13	Could you tell us about another project with reusing steel? — If ‘Yes’ please answer next questions, if not please jump to section ‘C. Potential for steel reuse’	a) Yes b) No

Table A2: Reuse of Structural Steel — Survey questions.

No.	Question	Choice
14	What was the motivation for reusing steel in your latest project?	a) Requested by the client b) Requested by the architect or designer c) Requested by the contractor d) Cost saving over new steel e) Carbon emissions reduction f) Other (please specify)
15	What tonnage of reuse steel was used in your latest project? — Could you specify?	a) 0 to 10 b) 10–100 c) 100–200 d) more
16	Did the reuse of steel result in cost savings or increases for your latest project? — If possible, please provide details.	a) Savings b) Increases c) Indifferent d) Not sure
17	Was the environmental benefit of reusing steel quantified in your latest project?	If possible, please provide details.
18	How easy was it to reuse steel in your latest project? — Please list the main difficulties encountered.	a) Easy b) Similar to new steel c) Difficult

Table A2: Reuse of Structural Steel — Survey questions.

No.	Question	Choice
	C. Potential for steel reuse	
19	List what you feel are three barriers to reusing structural steel elements for your company?	a) .... b) .... c) ....
20	List what you feel would be (or are) three benefits of reusing structural steel elements for your company?	a) .... b) .... c) ....
21	List what you feel would be (or are) three benefits of reusing structural steel elements for your company?	a) .... b) .... c) ....
22	How would you expect reusing steel to affect the cost of your company's activity?	a) Less expensive b) About the same c) More expensive

Table A2: Reuse of Structural Steel — Survey questions.

No.	Question	Choice
	Architects/Designers	
23	Would you consider specifying reused structural steel on a project if you could guarantee an adequate supply?	a) Yes b) No c) Not sure
24	From your perspective, what do you see as the major risks to using reclaimed structural steel? Please list three of them:	a) .... b) .... c) ....
25	Have you embarked on a project using reclaimed structural steel? — Please describe the project below.	a) Yes b) No
26	Is the certification of reused steel a significant barrier?	a) Yes b) No c) Not sure
27	Are there any specific tools, information or guidance that would make it easier to specify reused steel? Please list any below	a) .... b) .... c) .... d) .... e) ....
28	If you were specifying reused steel for a project, what information would you require on the condition, size and material properties of the reclaimed steel sections? Please list any below	a) .... b) .... c) .... d) .... e) ....

Table A2: Reuse of Structural Steel — Survey questions.

No.	Question	Choice
	Demolition/Deconstruction contractors	
29	Would you consider reclaiming structural steel from a project if you knew there was good demand for reused steel and it was commercially viable?	a) Yes b) No c) Not sure
30	If a building was designed for easy deconstruction, would you consider deconstructing it and collecting the steel elements for reuse?	a) Yes b) No c) Not sure
31	Would you be prepared to store reclaimed structural steel while waiting for a suitable project to come available? (For how long? What quantity of structural steel would you be prepared to store?	a) Yes b) No c) Not sure
32	From your perspective, what do you see as the major risks to using reclaimed structural steel? Please list three of them	a) .... b) .... c) ....

Table A2: Reuse of Structural Steel — Survey questions.

No.	Question	Choice
33	Is specialist equipment required to allow structural steel elements to be reclaimed from buildings? Please list any below	a) .... b) .... c) .... d) .... e) ....
34	1. At the pre-demolition tender stage, what information are you able to provide on the structural steel sections within the building, e.g. size, length, age, condition, steel grade, etc.? Please list any below.	a) .... b) .... c) .... d) .... e) ....
35	Would you be prepared to make this information publicly available (pre-demolition)?	a) Yes b) No c) Not sure
	Steelwork contractors	
36	Would you be open to work with reused structural steel if it was requested on a project?	a) Yes b) No c) Not sure
37	What do you see as challenges to fabricating new members from reclaimed sections? Please list three most important	a) .... b) .... c) ....

Table A2: Reuse of Structural Steel — Survey questions.

No.	Question	Choice
38	From your perspective, what do you see as the major risks to using reclaimed structural steel? Please list three of them.	a) .... b) .... c) ....
39	Would you be prepared to store reclaimed structural steel while waiting for a suitable project to come available? (For how long? What quantity of structural steel would you be prepared to store?	a) Yes b) No c) Not sure
40	What would your preferred procurement route, *i.e.* directly from a demolition contractor or from a stockholder?	a) Demolition contractor b) Stockholder
41	Is the certification of reused steel a significant barrier?	a) Yes b) No c) Not sure
	D. Final questions	
42	1. We would like to keep in touch with you about this survey. If this is agreeable to you, please provide contact information.	a) Name of Your Company: ... b) Name: ... c) Job Title: ... d) Division in the company: ... e) E-mail address:... f) Phone number:...