Reducing embodied carbon in the UK construction sector

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The challenge

Increasing output whilst substantially reducing carbon

> "Over the next 40 years the transition to low carbon can almost be read as a business plan for construction"

Paul Morrell - Chair of Steering Group, Innovation and Growth Team

Industry routemap

Requires 39% reduction in embodied carbon by 2050

The Low Carbon Routemap for the Built Environment

The **Green Construction Board**

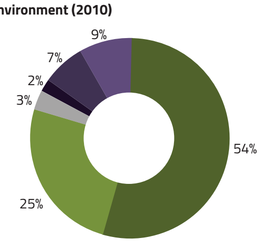
March 2013

The Green Construction Board has developed the Low Carbon Routemap for the Built Environment to serve as a visual tool enabling stakeholders to understand the policies, actions and key decision points required to achieve the UK Government target of 80% reduction in greenhouse gas emissions vs 1990 levels by 2050 in the built environment. The Routemap also sets out actions, together with key performance indicators that can be used to deliver and measure progress in meeting the 2050 target.

The Routemap covers both infrastructure and buildings sectors, and addresses segments of operational and capital (embodied) carbon emissions. The emissions covered by the Routemap are as follows:

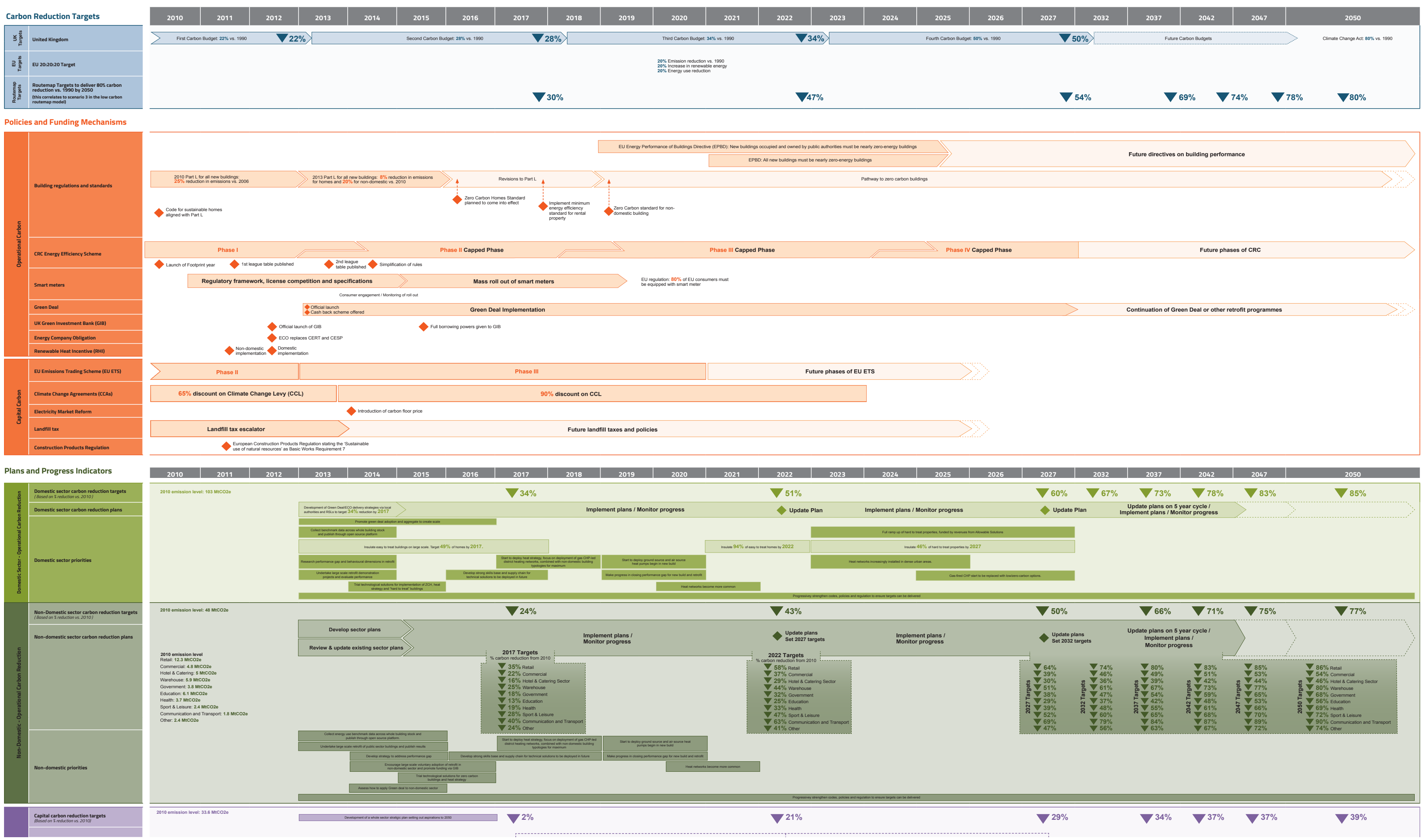
- Operational carbon in buildings: emissions from regulated energy use (excluding plug loads) for all domestic and non-domestic building sectors except industrial.
- Operational carbon in infrastructure: emissions from outdoor lighting, waste from construction, demolition and excavation, and water/wastewater. The use of transport infrastructure (by cars for example) is excluded. Some components of infrastructure that include buildings (such as railway stations) are included in the analysis, but appear under buildings.
- Capital carbon: covers emissions arising from the production and manufacture of materials (in the UK and abroad), transport of materials and people, all industry design and consultancy activities, and the emissions from on-site activities for the construction and demolition of buildings and infrastructure.

Breakdown of Carbon Emissions in the Built Environment (2010)



Key

- Domestic operational carbon
- Non-domestic operational carbon
- Infrastructure operational carbon
- Infrastructure capital carbon



Embodied carbon

Embodied carbon footprint of UK construction supply chain

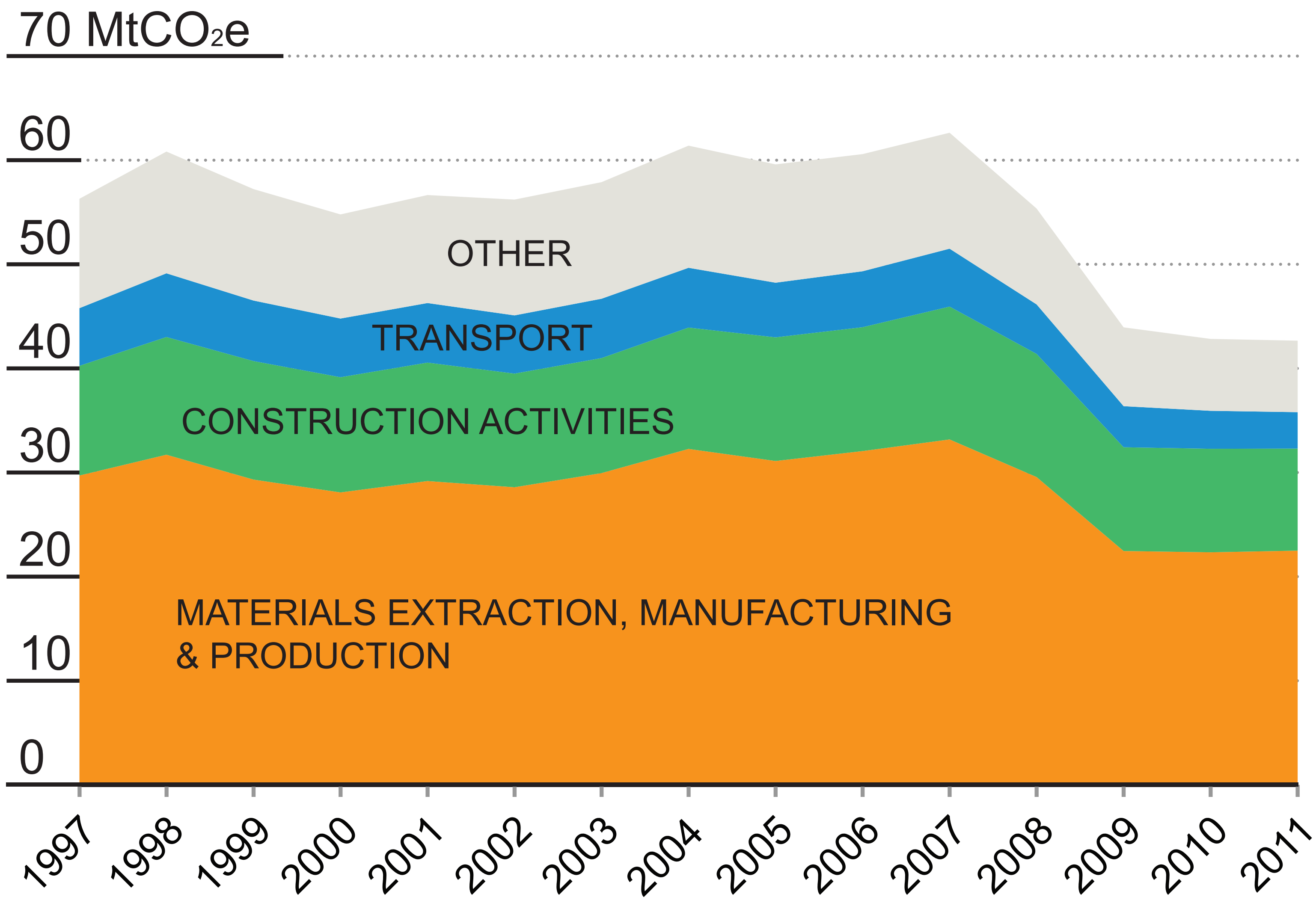
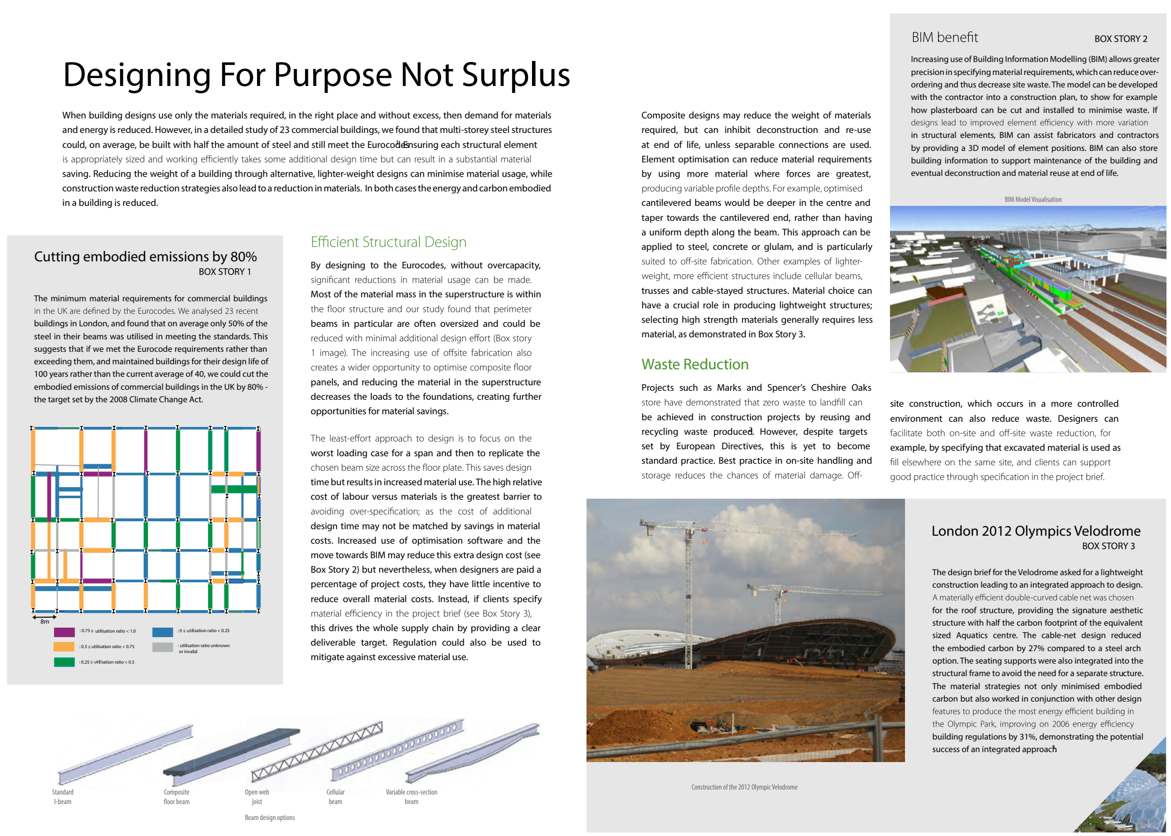


Figure from Giesekam et al. Energy and Buildings 78 pp202-214 (2014)

Strategies to reduce embodied carbon

Main strategies

- » Designing for purpose not surplus
- » Building life extension
- » Designing for deconstruction and re-use
- » Using alternative materials



Designing For Purpose Not Surplus

When building designs use only the materials required, in the right place and without excess, then demand for materials and energy is reduced. However, in a detailed study of 23 commercial buildings, we found that multi-storey steel structures could, on average, be built with half the amount of steel and still meet the Eurocodes[1]. Ensuring each structural element is appropriately sized and working efficiently takes some additional design time but can result in a substantial material saving. Reducing the weight of a building through alternative, lighter-weight designs can minimise material usage, while construction waste reduction strategies also lead to a reduction in materials. In both cases the energy and carbon embodied in a building is reduced.

Cutting embodied emissions by 80%

BOX STORY 1

The minimum material requirements for commercial buildings in the UK are defined by the Eurocodes. We analysed 23 recent buildings in London, and found that on average only 50% of the steel in their beams was utilised in meeting the standards. This suggests that if we met the Eurocode requirements rather than exceeding them, and maintained buildings for their design life of 100 years rather than the current average of 40, we could cut the embodied emissions of commercial buildings in the UK by 80% - the target set by the 2008 Climate Change Act.

Efficient Structural Design

By designing to the Eurocodes, without overcapacity, significant reductions in material usage can be made. Most of the material mass in the superstructure is within the floor structure and our study found that perimeter beams in particular are often oversized and could be reduced with minimal additional design effort (Box story 1 image). The increasing use of offsite fabrication also creates a wider opportunity to optimise composite floor panels, and reducing the material in the superstructure decreases the loads to the foundations, creating further opportunities for material savings.

The least-effort approach to design is to focus on the worst loading case for a span and then to replicate the chosen beam size across the floor plate. This saves design time but results in increased material use. The high relative cost of labour versus materials is the greatest barrier to avoiding over-specification; as the cost of additional design time may not be matched by savings in material costs. Increased use of optimisation software and the move towards BIM may reduce this extra design cost (see Box Story 2) but nevertheless, when designers are paid a percentage of project costs, they have little incentive to reduce overall material costs. Instead, if clients specify material efficiency in the project brief (see Box Story 3), this drives the whole supply chain by providing a clear deliverable target. Regulation could also be used to mitigate against excessive material use.

Beam design options

Composite designs may reduce the weight of materials required, but can inhibit deconstruction and re-use at end of life, unless separable connections are used. Element optimisation can reduce material requirements by using more material where forces are greatest, producing variable profile depths. For example, optimised cantilevered beams would be deeper in the centre and taper towards the cantilevered end, rather than having a uniform depth along the beam. This approach can be applied to steel, concrete or glulam, and is particularly suited to off-site fabrication. Other examples of lighter-weight, more efficient structures include cellular beams, trusses and cable-stayed structures. Material choice can have a crucial role in producing lightweight structures; selecting high strength materials generally requires less material, as demonstrated in Box Story 3.

Waste Reduction

Projects such as Marks and Spencer's Cheshire Oaks store have demonstrated that zero waste to landfill can be achieved in construction projects by reusing and recycling waste produced[2]. However, despite targets set by European Directives, this is yet to become standard practice. Best practice in on-site handling and storage reduces the chances of material damage. Off-site construction, which occurs in a more controlled environment can also reduce waste. Designers can facilitate both on-site and off-site waste reduction, for example, by specifying that excavated material is used as fill elsewhere on the same site, and clients can support good practice through specification in the project brief.

BIM benefit

BOX STORY 2

Increasing use of Building Information Modelling (BIM) allows greater precision in specifying material requirements, which can reduce over-ordering and thus decrease site waste. The model can be developed with the contractor into a construction plan, to show for example how plasterboard can be cut and installed to minimise waste. If designs lead to improved element efficiency with more variation in structural elements, BIM can assist fabricators and contractors by providing a 3D model of element positions. BIM can also store building information to support maintenance of the building and eventual deconstruction and material reuse at end of life.

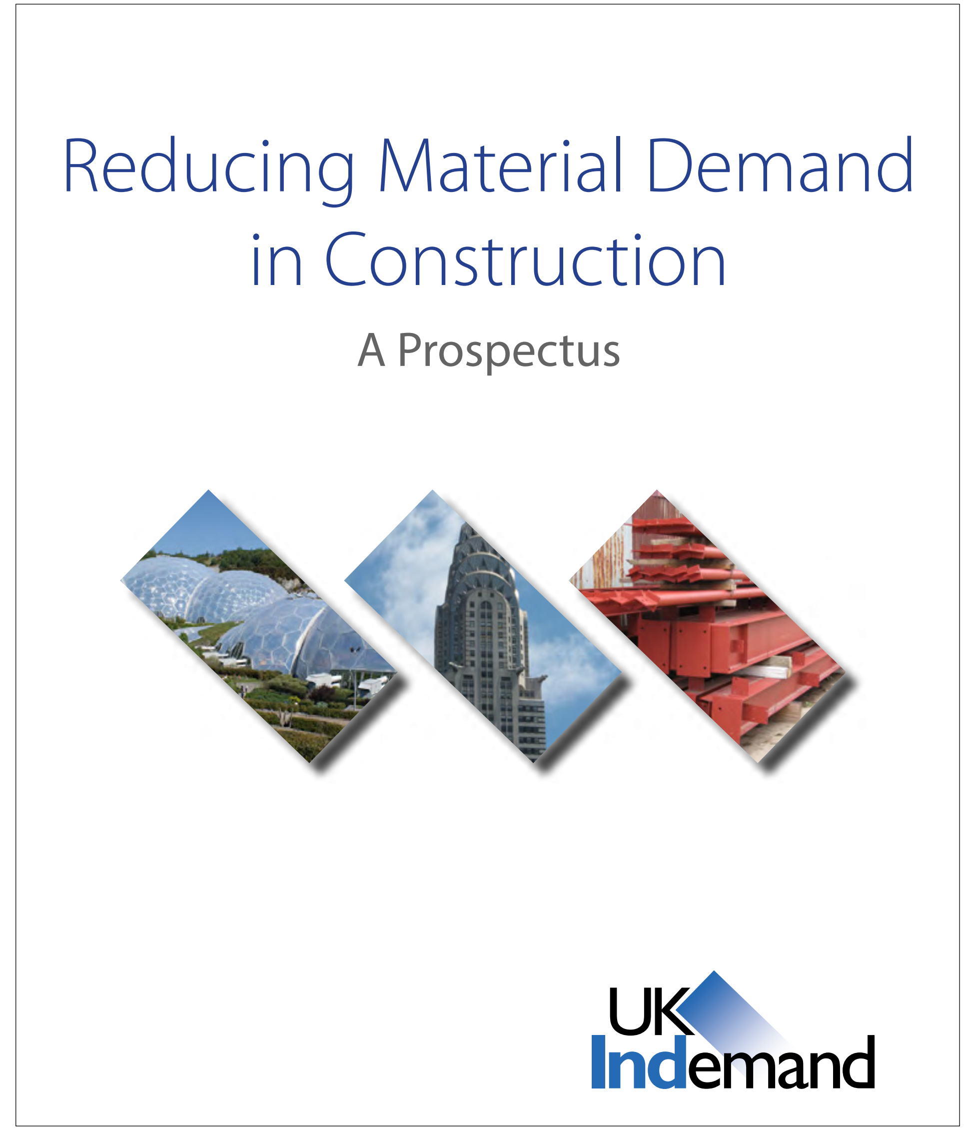
BIM Model Visualisation

Construction of the 2012 Olympic Velodrome

London 2012 Olympics Velodrome

BOX STORY 3

The design brief for the Velodrome asked for a lightweight construction leading to an integrated approach to design. A materially efficient double-curved cable net was chosen for the roof structure, providing the signature aesthetic structure with half the carbon footprint of the equivalent sized Aquatics centre. The cable-net design reduced the embodied carbon by 27% compared to a steel arch option. The seating supports were also integrated into the structural frame to avoid the need for a separate structure. The material strategies not only minimised embodied carbon but also worked in conjunction with other design features to produce the most energy efficient building in the Olympic Park, improving on 2006 energy efficiency building regulations by 31%, demonstrating the potential success of an integrated approach[3].



Barriers to use of alternative materials

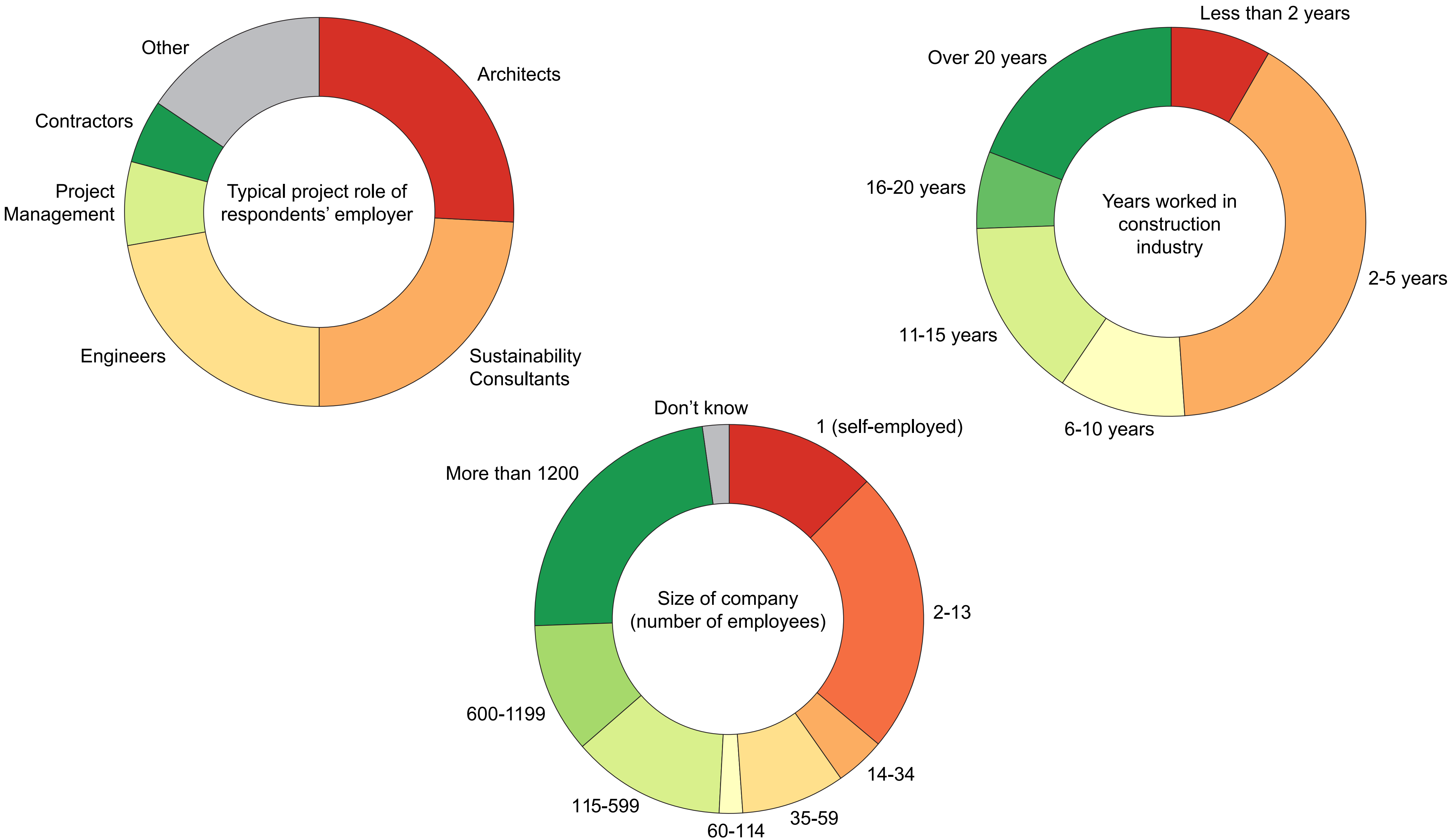
There are too many to talk about in 10mins

Institutional and Habitual	Economic	Technical and Performance-related	Knowledge and Perceptions
Institutional culture and established practice promotes preferred material palette Focussed training and recruitment results in departmental lock in to familiar materials Time constraints incentivise familiar 'copy-paste' designs Lack of established advocacy groups Lack of effective marketing from producers Lack of user-producer relationships Influence of industry trends Habitual specification and historic practice of individual practitioners Viewed as outwith responsibility or remit of any individual High level of design inconvenience	High cost of new products Market externalises cost of embedded emissions Uncertainty premium placed on novel options High transaction costs of additional professional training and research Money sunk in existing materials (in terms of training, establishing relations with supply chains etc.) Lower design:fee ratio because of increased detailing Insufficient comparative information on costs Unwillingness to accept risk Project financing incompatible with time constraints Anticipated increase in lead times Small industries producing alternatives cannot compete against established industries' economies of scale	Lack of established standards, design guides and tools, and standardised details Lack of material performance data Lack of full-scale demonstration projects Policy and regulatory limitations and restrictions Lack of confidence in contractor ability and availability of skilled labour prevents inclusion in design Shortage of specialist skills prevents installation Insufficiently developed supply chains Local availability of materials and technologies	Lack of awareness and practical knowledge of alternatives amongst practitioners Lack of client knowledge of alternatives Negative perceptions amongst practitioners based on past experiences Negative perceptions held by clients Insufficient fit with the culture of the clients/inhabitants Perceived unreliability or risk of new alternatives Perceived concerns about material sourcing prevent selection Policy uncertainty Regarded as low priority and other considerations take precedence

Table from Giesekam et al. Energy and Buildings 78 pp202-214 (2014)

Survey Demographics

47 responses, range of professions, companies and experience



Results

Principal barriers

» **Perception of high costs**

» **Lack of early engagement with supply chain**

» **Lack of quality benchmark data**

» Dearth of knowledge, understanding and skills

» Availability of product carbon information

» Insufficient allocation of responsibility for embodied carbon reduction

» Industry culture

» Low value of materials

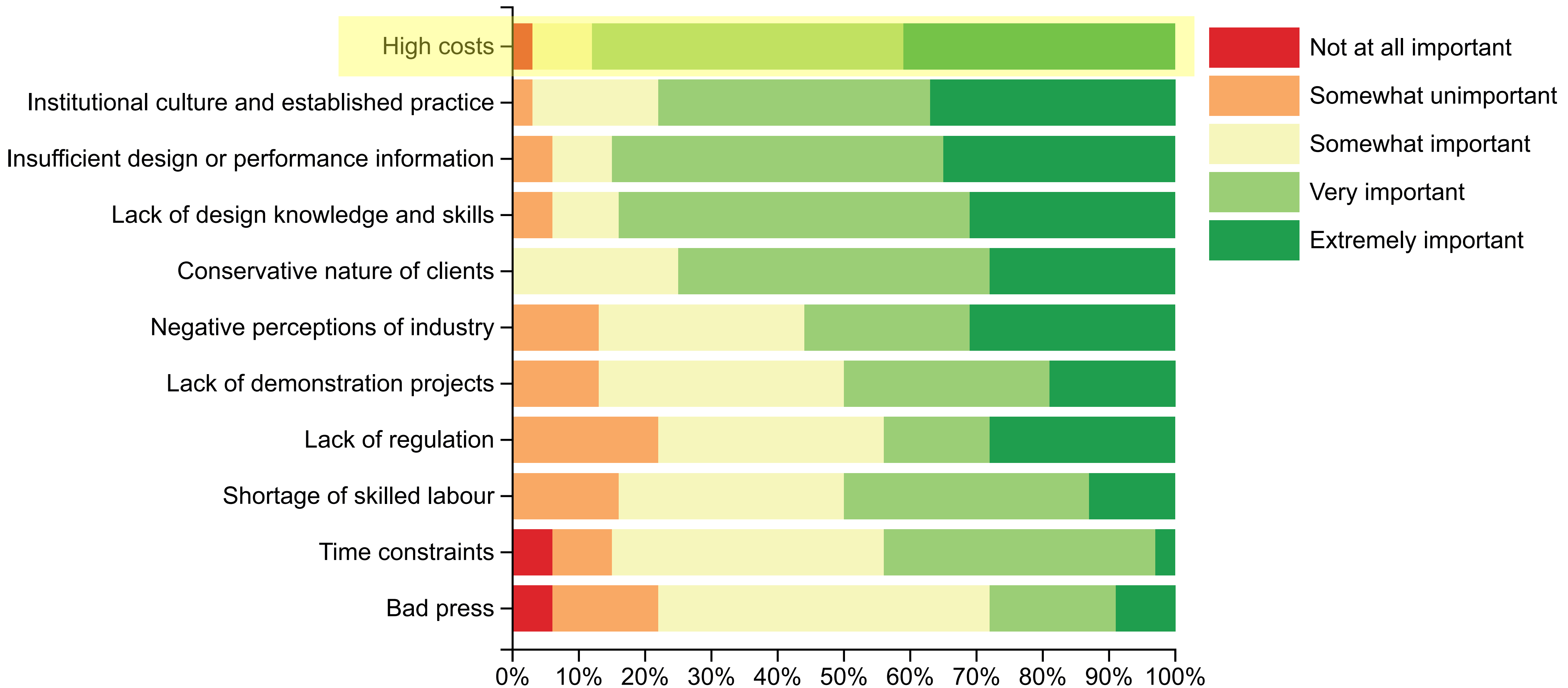
» Negative perceptions of low carbon materials

» Lack of demonstration projects and product testing

Survey Results

Barriers

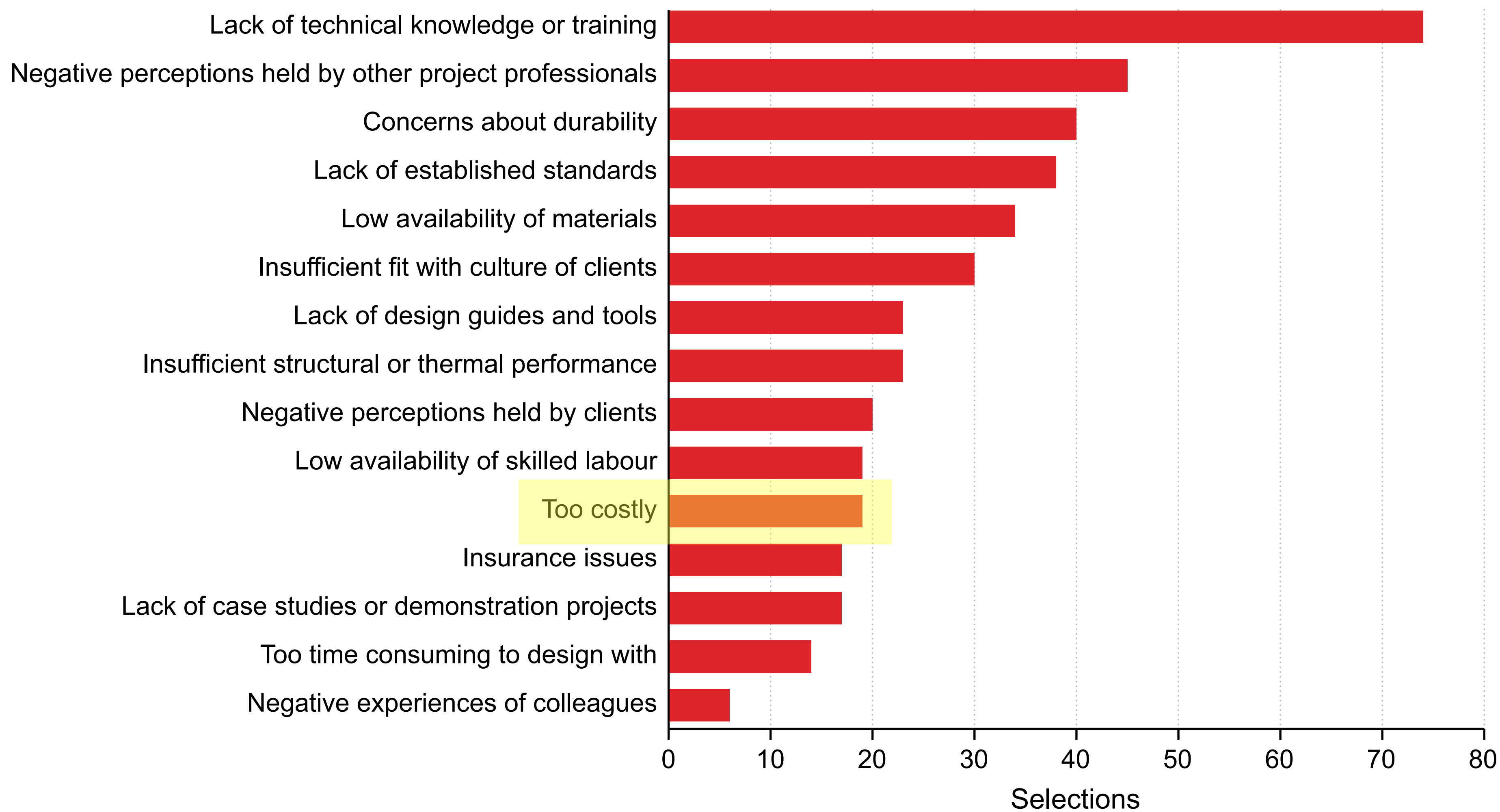
Q19. Thinking more generally about alternative materials in construction, how important do you believe the following factors are in preventing their use?



Survey Results

Barriers

Q17. You stated that you are aware of but have not used the following materials on a project. Why have you chosen not to use these materials?



Interview Results

Early consideration and engagement is essential

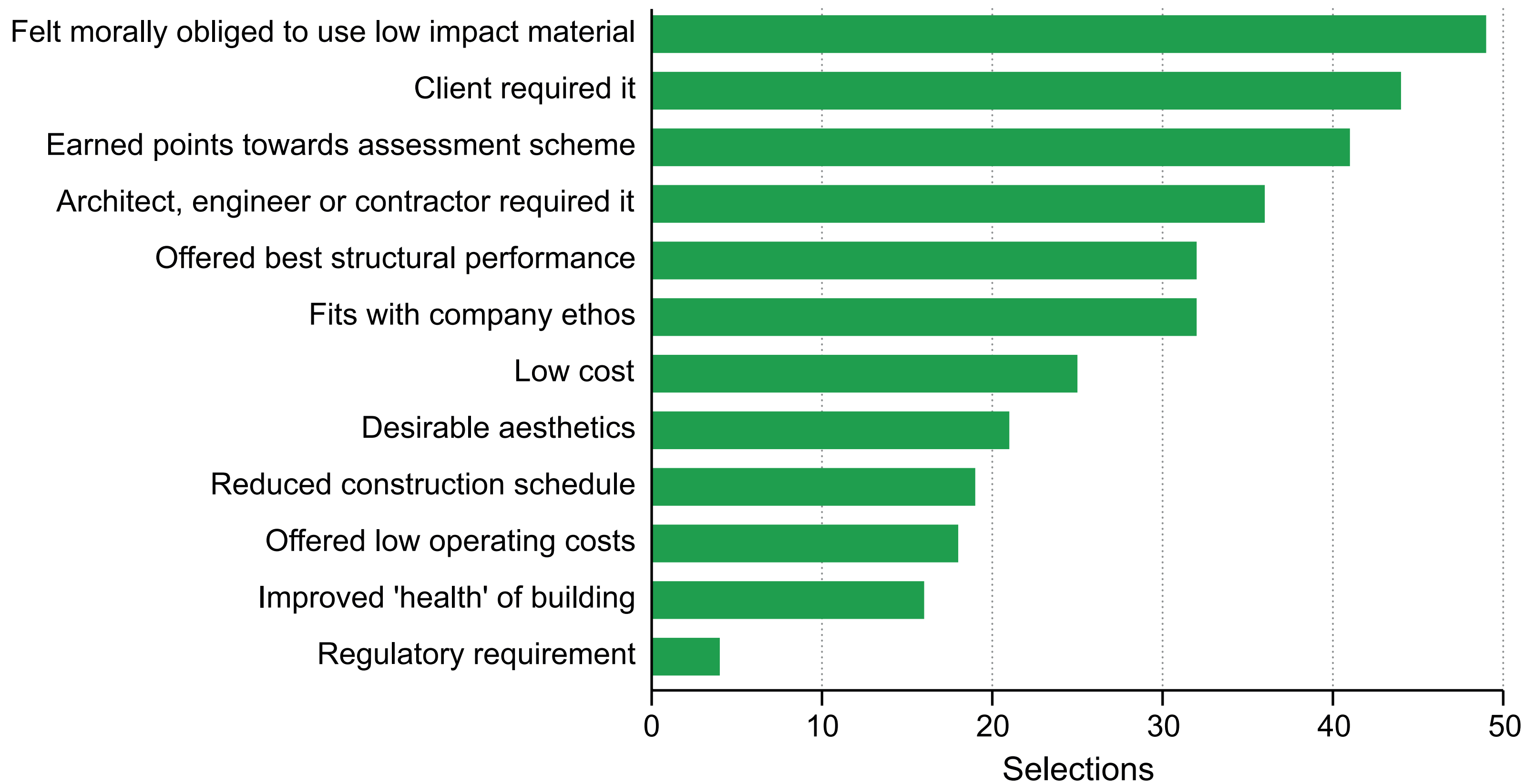
"there are a lot of opportunities missed by not thinking about things holistically all the way through the process. There's diminishing returns the later you start considering these things, the less reduction you're going to achieve and probably the more it is going to cost...that's one of the biggest barriers, people think it'll cost more...sometimes it might but often it won't if you just took the time to think about it."

Senior Engineer - large multidisciplinary consultancy

Survey Results

Drivers

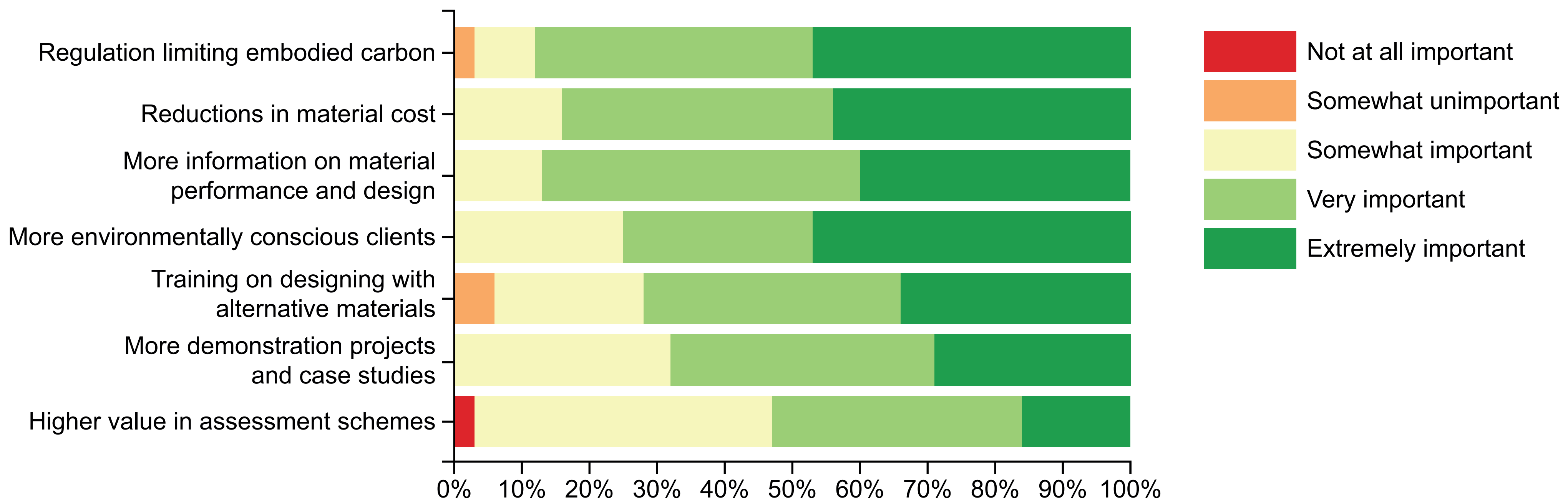
Q13. Thinking about the projects on which you used these materials. Why did you choose to use each material?



Survey Results

Drivers

Q21. How important do you believe the following developments could be in encouraging greater use of alternative materials and construction products?



Interview Results

Regulation is required

"I think we need to make sure that the regulations make it happen. Without that it'll be left to the moral leaders to continue their work but it won't become an industry."

Chair of Embodied Carbon Task Force

Aligning benchmarks with targets

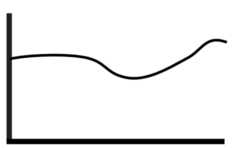
Proposed Buildings Embodied Carbon Model

Construction Sector Total Emissions ← Constrained by IO Model

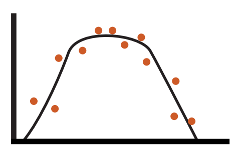
Building typologies
Total emissions by type ($MtCO_2e$)

For each building type

Volume of construction
Demand profile based on financial value and/or total area of annual output. (£ or m^2)



Typical carbon footprint
Function representing range of observed values in appropriate functional unit e.g. CO_2e/m^2 NIA. Based upon case studies and WRAP database.



Range of achievable reductions
Possible reductions based upon case studies. Measured in the corresponding functional unit.

e.g. 10% reduction or 70 $kgCO_2e/m^2$ achieved

Model will initially be calibrated against data from past decade using UK MRIO time series and observed volumes of construction.

Summary

Early action on embodied carbon is required

- Embodied carbon emissions from construction are substantial and growing
- Morals and clients are increasingly driving the use of low carbon materials
- Many barriers must be overcome to increase uptake of alternative strategies
- Business case must be developed and more widely disseminated
- Additional regulation is needed - there is an ongoing debate on how and when
- More data is needed to establish robust benchmarks for designers
- Benchmarks must ultimately be linked to long term targets
- Practitioners want increased engagement from professional institutes
- Opportunity to develop an industry with significant export potential
- Opportunity for sizeable reductions in carbon emissions in short order