

Building

COSTING STEELWORK #1

OFFICES FOCUS

COSTING STEELWORK

HOW TO COST STEEL FRAMED BUILDINGS

● Costing Steelwork is a new series from Aecom, BCSA and Steel for Life that provides guidance on costing structural steelwork

About the Costing Steelwork series

Published each quarter, Costing Steelwork will examine the key cost drivers for different sectors, provide a building type-specific cost comparison and include a cost table, which indicates cost ranges for various frame types.

These cost ranges can be used at all design stages to act as a comparative cost benchmark. Subsequent articles will provide updates to ensure the data remains current.

The series will comprise studies into office, education, mixed-use, retail and industrial buildings. This article focuses on the offices sector, examining the process of cost planning throughout the design stages, the key steel framing cost drivers for office buildings, and providing a detailed cost model based on an actual office building.

A key component of the cost of any building type is the frame, which, for multi-storey buildings, accounts for approximately 10% of the overall building cost. The accuracy of any costing exercise depends on the level of design information on which it is based. As the design develops and more information becomes available, the extent to which the cost can be detailed increases.

RIBA STAGE 1-2

The budget set at the early stages of the design needs to reflect the final build cost despite limited information being available. This means rates used during this phase need to include items which are not yet quantifiable.

At this critical stage in the project, much of the decision making on the frame construction method takes place. The steel frame design is represented as a relative weight (kg/m^2) as opposed to a framing layout with beam sizes. Costs and rates based on a kg/m^2 design intent should consider the following:

- The steelwork quantity based on gross internal floor

area (GIFA) or relative areas that the steel frame covers, which will depend on the building type and loading requirements

- How the kg/m^2 benchmarks against similar buildings
- If the quantity of steel (kg/m^2) accounts for fittings and steel-to-steel connections or whether an additional allowance needs to be made
- The potential mix of steel members: columns, beams, fabricated sections etc
- Consideration of the fire protection method and fire rating
- Non-standard details such as cantilevers and transfers
- The erection and lifting strategy and whether there will be a need for some members to be erected with mobile rather than tower cranes.

In addition, typical items that would not be covered in primary steelwork (kg/m^2) but will need to be considered include:

- Secondary steelwork including framing to risers, lifts and cladding
- Connections to concrete or existing structures.

Following consideration of all of the above a “blended all in” rate is then derived and applied to the calculated kg/m^2 . These rates will then be reviewed against similar projects and steel frame types which provide analysis against benchmarks.

Market testing should also be sought through consultation with steelwork contractors to ensure the accuracy of rates, forming a credible foundation for the steelwork costings to be developed in the subsequent design stages.

RIBA STAGE 3-4

As the design progresses, technical information from the structural engineer on the proposed frame will become available, allowing a more accurate and developed quantification of the frame cost, which will now include a piece count and review of the design evolution.

Other information likely to become available at this stage includes:

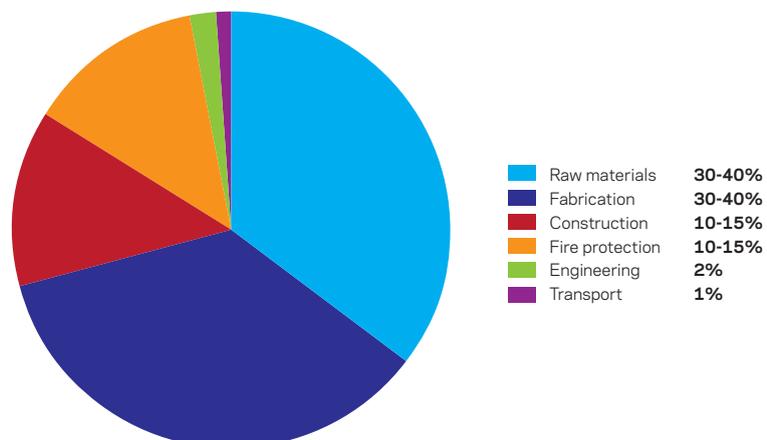
- Drawings showing the frame configuration
- Cores and shear walls
- Column and beam sizes and types
- Floor construction details
- The strategy for integration of mechanical and electrical services.

The developing steel frame design can then be broken down into three components:

- Main members: primary supports that carry the loads, such as beams, columns and trusses
- Secondary members: those carrying specific loads
- Fittings and connections: bracing, stiffeners and the joints that transfer forces between the structural elements
- Miscellaneous: items such as temporary steelwork, metal decking to composite floors, stairs, riser decking, external core angles, tower crane grillages, and stubs for BMU tracks.

It is still important at this stage in the design process to continue to determine and redress what has not been included within the drawings and

Figure 1: Breakdown of costs of a steel frame for a typical multi-storey office building



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ensure that these missing elements are taken into account. For example, the extent of secondary members should not be overlooked as these can account for a significant proportion of the overall steel piece count and cost.

To calculate the cost of the structural frame, each of the components noted above will have a rate per tonne applied and then totalled. This rate should include the raw materials, fabrication, construction, fire protection, engineering and transport costs (Figure 1).

There are risks and limitations in cost planning steelwork based on a simple rate per tonne, as this does not take into account specific features such as long-span beams, cranking or tapering, curvature of steel, hollow sections, cantilevers, irregularity of grid, back propping and movement connections, all of which may require an adjustment to the basic applied steelwork rate.

SOURCING COST INFORMATION

When estimating and cost planning buildings it is important to assess the relevance of the source cost information. If this is sourced from previous projects then the base date and building form must be considered and compared between the current and past projects.

Figure 2 represents the costs associated with the structural framing of a commercial office development in central London expressed as a cost/m² on GIFA. It should be used for comparative purposes to provide a benchmark. The range of costs represents the variances in the key cost drivers, as noted later in the article. If a building's frame cost sits outside these ranges this should act as a prompt to interrogate the design and determine the contributing factors.

The location of a project is a key factor in price determination and indices are available to enable the adjustment of cost data across different regions. The variances in these indices, such as the BCIS location factors (Figure 3), highlight the existence of different market conditions in different regions, which must not be overlooked.

To use the tables:

1. Identify which frame type most closely relates to the project under consideration
2. Select and add the floor type under consideration
3. Add fire protection if required.

For example, for a low-rise office building with a composite metal deck floor and 60 minutes fire resistance, the overall frame rate (based on the average of each range) would be:

$$£126.5 + £92.5 + £21.5 = £240.5 \text{ per m}^2 \text{ GIFA}$$

The rates should then be adjusted (if necessary) using the BCIS location factors appropriate to the location of the project.



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Figure 2: Indicative cost ranges based on gross internal floor area

TYPE	Central London (£/m ²)	Notes
Frames		
Steel frame to low-rise office	115-138	Steelwork design based on 55kg/m ²
Steel frame to high-rise office	195-220	Steelwork design based on 90kg/m ²
Complex steel frame	220-260	Steelwork design based on 110kg/m ²
Floors		
Composite floors, metal decking and lightweight concrete topping	75-110	Two-way spanning deck, typical 3m span with concrete topping up to 150mm
Precast concrete composite floor with concrete topping	115-165	Hollowcore precast concrete planks with structural concrete topping, spanning between primary steel beams
Fire protection		
Fire protection to steel columns and beams (60 minutes resistance)	18-25	Factory applied intumescent
Fire protection to steel columns and beams (90 minutes resistance)	20-35	Factory applied intumescent

Figure 3: BCIS Location Factors, as at Q1 2017

Location	BCIS Index	Location	BCIS Index
Central London	125	Nottingham	93
Manchester	99	Glasgow	93
Birmingham	98	Newcastle	92
Liverpool	96	Cardiff	91
Leeds	95	Dublin	90*

*Aecom index

MARKET UPDATE

● As input costs for all industries rise, there have been significant changes to the cost of building materials in recent months

Input costs for all industries are rising at their fastest rate since 2008, according to the government's producer price inflation indices. Building materials, particularly those where imports are high, saw notable changes over the latter quarters of 2016 (Figure 4). The Department for Business, Energy and Industrial Strategy's latest building materials bulletin records these emerging changes, rising nearly 4% over the year to December 2016.

Commodity prices, which provide inputs to many construction materials, have also seen rises, with forecasts of more increases through 2017. The World Bank's latest forecasts suggest upwards of 10% increases set for this year, although there is both downside and upside risk to this forecast.

TENDER PRICE TRENDS

Building prices rose in Q1 2017 by 4.6% from Q1 2016 according to Aecom's tender price index (Figure 5), which uses Greater London as a base location. Although now slowing, this yearly rate of change maintains a level that is higher than the long-run averages for tender price inflation and pushes the index to new highs. Uncertainty has increased throughout the industry but its effect on actual market pricing has so far been muted.

Material costs are continuing to rise although it is expected that this will be at a slower rate over the next 24 months. Nevertheless, lower expected UK construction output will add some downward pressure on pricing.

Construction labour rates also continue to rise on a yearly basis. Domestic inflation will add further complications to the input cost mix, which has arisen from significant changes to exchange rates. Together, these forces add to a build-up of pressure in the construction value chain and pricing. If sterling remains weak for an extended period, domestic inflation is likely to rise over the year, as is wage growth.

Aecom's baseline forecasts for tender price inflation are 3.2% from Q4 2016 to Q4 2017, and 1.9% from Q4 2017 to Q4 2018. Upside risks to pricing have increased, reflecting the pressures from domestic inflation combined with somewhat better than expected construction output post-EU referendum. Downside risks on pricing are evident later in the forecast period.

The forecasts for tender price inflation are

Figure 4: Material price trends

Price indices of construction materials 2010=100. Source: Department of Business, Energy and Industrial Strategy

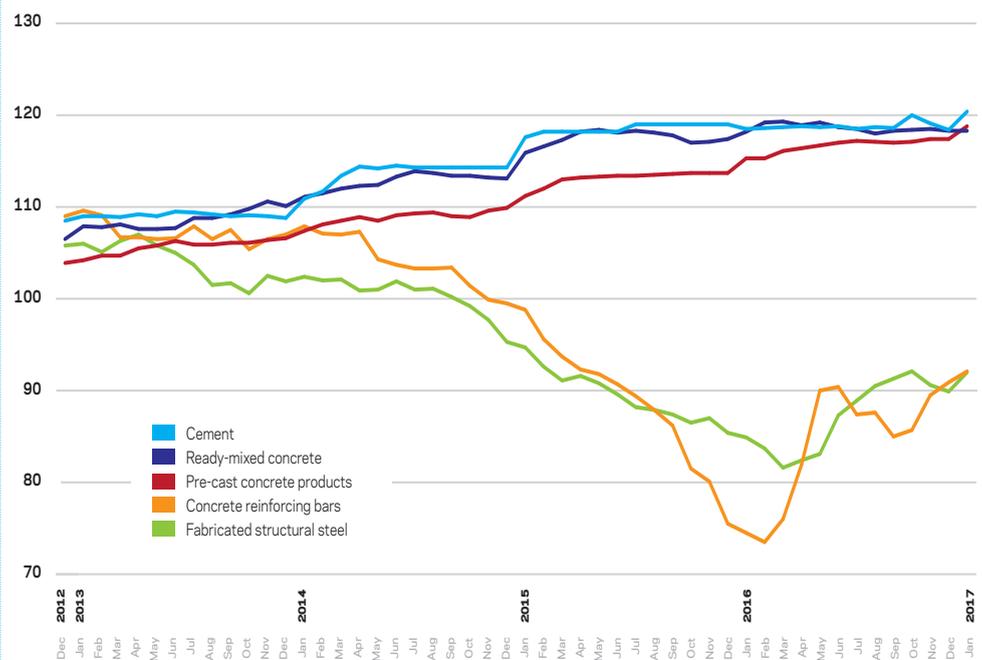


Figure 5: Tender price inflation, Aecom Tender Price Index: 1976=100

Quarter	2014	2015	2016	2017	2018	2019	2020
1	467	492	542	567	582	592	612
2	464	505	552	573	585	595	618
3	474	520	557	577	588	600	624
4	482	532	561	579	590	606	630

based on a number of key assumptions: construction output continues a flat trend; Brexit-related events in the short term continue to ignore the more pessimistic forecasts of an immediate and sustained downturn, but over the medium-term risks do weigh to the downside;

order books remain firm but uncertainty begins to increase in the second half of 2017 and into 2018; prevailing trends in government capital expenditure are not substantially changed in the short-term; and sterling strengthens moderately.





KEY COST DRIVERS AND ISSUES FOR COMMERCIAL BUILDINGS

Once the design has developed sufficiently to cost the specific building design rather than utilising typical ranges, key cost drivers remain important for making sure a realistic cost is included within the cost plans. There are a number of unique design aspects that need to be taken into account for commercial buildings. These factors could also be used to drive cost efficiencies. A number of these factors are focused on the weight of steel but there are other influencing factors which can have a significant impact on costs.

■ **Core options** Whether the core is constructed from concrete or steel will have varying cost impacts on the steel frame. A concrete core will mean introducing an additional trade. This will need to be factored into the steel frame installation programme and may occasionally result in shared tower crane usage. An additional consideration will be the requirement to cast in fixings and site welding fin plates to allow steel to concrete connections, which should be factored into the costs. In comparison, a braced steel core is a lightweight and flexible solution when compared with the concrete equivalent. The key cost drivers in this instance will include an increased installation piece count, which will consist of relatively lightweight profiles. These have a direct bearing on the associated rate (£/tonne). The effect of a lightweight steel core on foundation costs should also be considered.

■ **Floorplate configuration** When deciding on floorplate configuration it is important to understand the drivers for the desired layout and the potential cost implications of this choice. Floorplate configuration can vary across projects and can be influenced by a range of factors, for example, the design aspiration and/or site constraints. The simplest option is to adopt a regular framing layout where the steel to steel connections are at 90 degrees, which allows for a more straightforward construction. In contrast, adopting an irregular layout has the potential to affect the fabrication costs as this approach will require splayed connections and necessitate increased cutting of the floor deck. Another consideration is curved floor plates, which can incur cost premiums as a result of increased manufacturing processes and wastage.

■ **Repetition** The absence of repetition of the floorplate stack should also be considered as it will lead to the requirement of a transfer structure, increasing costs. Alignment must also be considered. If there is a lack of column alignment this may result in the introduction of localised transfers. As well as impacting the costs this could compromise the services zone.

■ **Security/Robustness** Design requirements to strengthen the frame in response to the building's security assessment rating will mean increased structural demands on connection details and edge beams, particularly at the lower levels of the building, eg provision for column removal without progressive collapse of the building.

■ **Floor response factor** For most multi-storey commercial buildings, straightforward steel construction will meet the required vibration performance criteria without modification. However, stiffening may be required to meet particularly onerous floor vibration design criteria, in which case deeper and heavier beams would be needed.

■ **Structural zone** There is an optimum structural zone where beams work efficiently. However, with the introduction of services and the desire to increase floor-to-ceiling heights this zone can become compromised. The reduced structural zone may make the frame less efficient and increase steel member weights.

■ **Service integration** When penetrations are required within the beam depth to allow services to distribute throughout the floorplates, the size and positioning of these can have an impact on the performance of the beam. Ductwork distribution can result in oversized penetrations; should this occur there will be a requirement to stiffen the holes in order to maintain the integrity of the beam. This involves the welding of additional plates and angles to the beam. The effect of service integration in terms of reduced overall building height should also be considered.

■ **Erection of steelwork** The erection of steelwork is reliant on crane hook time; therefore, multiple small beams will have a disproportionately high erection cost when compared against a large single beam. Tower cranes are the main source of lifting on site. Crane capacity should be factored in to the logistics strategy as any individual members that exceed the tower crane capacity will need to be erected by utilising mobile cranes (with their associated road closures and space requirement). In cost planning buildings, allowances should be made for tower cranes with sufficient capacity to lift the majority (if not all) of the components necessary to construct the building. Where specific specialist lifts are required then allowance needs to be included within the overall building budget (this is not specific to steel framing and should be taken into account when considering the building as a whole).

■ **Fire protection** The first thing that needs to be established is what fire rating is required (60, 90 or 120 minutes). Next the proposed method of applying the fire protection should be considered – off-site applied thin film intumescent coatings are commonplace particularly as it removes work from site. However, other methods are available such as boarded, on-site applied cementitious coating or concrete encasement. When approaching the costs and making comparisons, programme effects need to be factored into the overall cost planning process.

■ **Logistics and programming** Site conditions have a direct impact on costs which manifests itself in the erection and package-specific preliminaries costs. In extreme cases the site conditions determine the design solution, eg constructing above railway lines, sites adjacent to or over rivers, or sites with restricted access (double handling). Site-specific preliminaries are influenced by tower crane availability, building height, uniformity of grid, on site welding requirements, delivery timings and quiet periods.

■ **Market influences** External factors such as currency exchange rates, buoyancy of the market, labour availability and commodity prices all influence market dynamics and as such should be considered at the time of developing the cost plan. It is advisable always to include exchange rates in the basis and assumptions of the cost document.

COST COMPARISON: OFFICE

● This quarter's office cost comparison costs a 10-storey grade A building in central London

The building used for the cost model is a multi-storey office structure; One Kingdom Street, London. The project is located in the Waterside regeneration area near Paddington railway station in Central London. This Grade A office building was completed in 2008.

The building's key features are:

- 10 storeys, with two levels of basement
- Typical clear spans of 12m x 10.5m

- Three cores - one main core with open atrium, scenic atrium bridges and lifts

- Plant at roof level

This building was originally part of the Target Zero study conducted by a consortium of organisations including Tata Steel, Aecom, SCI, Cyril Sweett (now Currie & Brown) and BCSA in 2010 to provide guidance on the design and construction of sustainable, low and zero-carbon buildings in the UK.

This cost comparison updates the cost models developed for the Target Zero project and provides up-to-date costs for the two alternative framing solutions considered.

ABOUT THE BUILDING

As noted in the original Target Zero study, the building accommodates 24,490m² of open-plan office space on 10 floors and, on the eastern half of the building, two basement levels providing car parking and storage. The gross internal floor area is 33,018m². The 40m-high building is rectilinear with approximate dimensions of 81m x 45m. The front facade faces north and comprises a reverse ellipse along the length of the building plan on podium and first floor levels.

One Kingdom Street has three cores and is designed around two central atriums on its southern elevation, which house six scenic wall chamber lifts. The western half of the building is partly constructed on a podium transfer structure enclosing works access for Crossrail.

One Kingdom Street has a steel frame, on a typical 12m x 10.5m grid, comprising fabricated cellular steel beams supporting a lightweight concrete slab on a profiled steel deck. The larger span is dictated by the location of beams within the Crossrail podium deck on which they are supported. The steel beams are designed to act compositely with the concrete floor slabs through the use of welded shear studs.

The cellular floor system enables the services to be integrated within the structural zone, ie within web openings in the beams. The clear floor-to-ceiling height in the office areas is 2.8m. Upper floors support a 175mm raised floor and a perforated metal tile suspended ceiling incorporating acoustic insulation.

The foundations comprise 750mm diameter bored-piled foundations with insitu concrete pile caps. Ground beams provide lateral restraint to the pile caps. The piles are the same size as those used to support the existing Crossrail podium in order to reduce potential differential settlement arising from the use of different pile diameters.

The office areas are clad with an anodised aluminium curtain walling system consisting of storey height double-glazed windows units on a 1.5m module. Vertical fins at 3m centres support the external aluminium louvres for solar shading on the southern elevation and part of the east and west elevations.





COST COMPARISON

Two structural options for the office building were assessed: the base case as described above and a 350mm thick post-tensioned concrete flat slab with a 650 x 1050mm perimeter beam.

The full building cost plans for each structural option have been reviewed and updated to provide current costs at Q1 2017. The costs, which include preliminaries, overheads, profit and a contingency, are summarised in Figure 6.

The analysis shows that the cost of the steel composite solution was 7% lower than the post-tensioned concrete flat slab alternative in terms of the frame and upper floors, and 5% lower on a total building basis.

Figure 6: Key costs £/m² (GIFA), for Central London office building

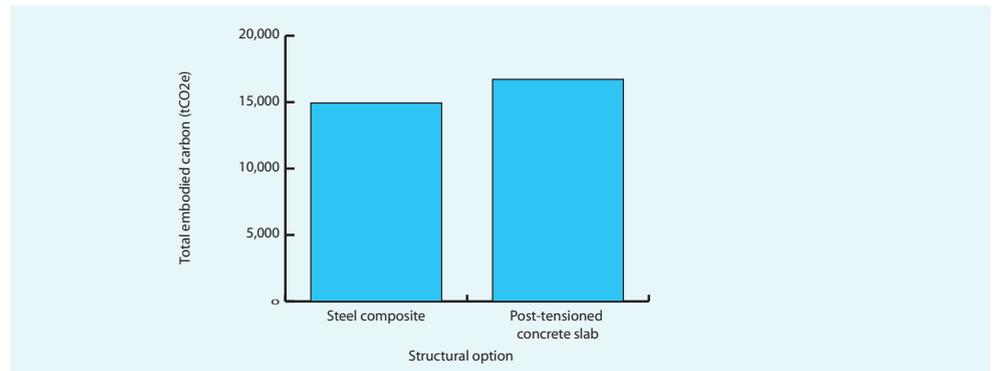
Elements	Steel composite, key costs £/m ²	Post-tensioned concrete flat slab, key costs £/m ²
Substructure	84	89
Frame and upper floors	402	433
Total building	2,485	2,612

EMBODIED CARBON COMPARISON

The original Target Zero project also included a comparison of the embodied carbon of the two framing solutions. This was on a “cradle-to-cradle” basis that included the manufacture and transport of construction materials, the construction process and the demolition and disposal of the building materials at the end-of-life.

The results, which are presented in Figure 7 showed that the embodied carbon of the steel composite solution was 11% lower than the post tensioned concrete flat slab alternative.

Figure 7: Embodied carbon comparison



KEY COST ADVANTAGES OF STEEL FRAMING

- **Column-free floorplates** Steel framing is an economic means of providing long spans without the requirement for intermediate columns, thus creating increased open plan space which is advantageous to office building letting.
- **Adaptability** Tenant alterations are considerably less complex with steel framed buildings, particularly major alterations such as the introduction of internal accommodation stairs or double-height spaces.
- **Off-site manufacture** This results in a reduction in on-site labour, which as a consequence reduces health and safety risks.
- **Services integration** The integration of services within the structural elements of buildings leads to economies in construction by reducing the floor-to-floor height, which has a double benefit of reducing the external cladding required and also reducing heat loss through the envelope. In multi-storey buildings, service integration can allow extra floors to be provided within the same overall building height.
- **Lightweight** The reduced weight of a steel framed building has a beneficial effect on the foundation design. It also allows the building to be constructed over restricted load areas such as railway station boxes and transfer structures.
- **Programme** Steel frame installation and its ability to be pre-manufactured offers programme advantages due to certainty of delivery and speed of installation.

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