WEBB YATES ENGINEERS

POLYCOR

THE STONEMASONRY COMPANY LIMITED

eight associates

GROUPWORK

jackson coles

Stone Tower Research Project

Cost Consultants – Jackson Coles

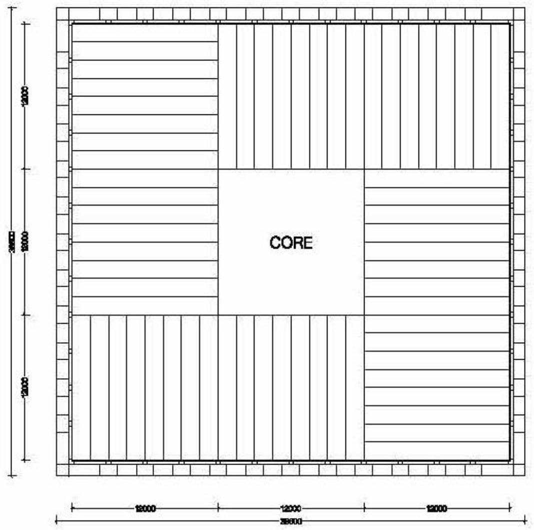
Sustainability – Eight Associates

Structural Engineering – Webb Yates

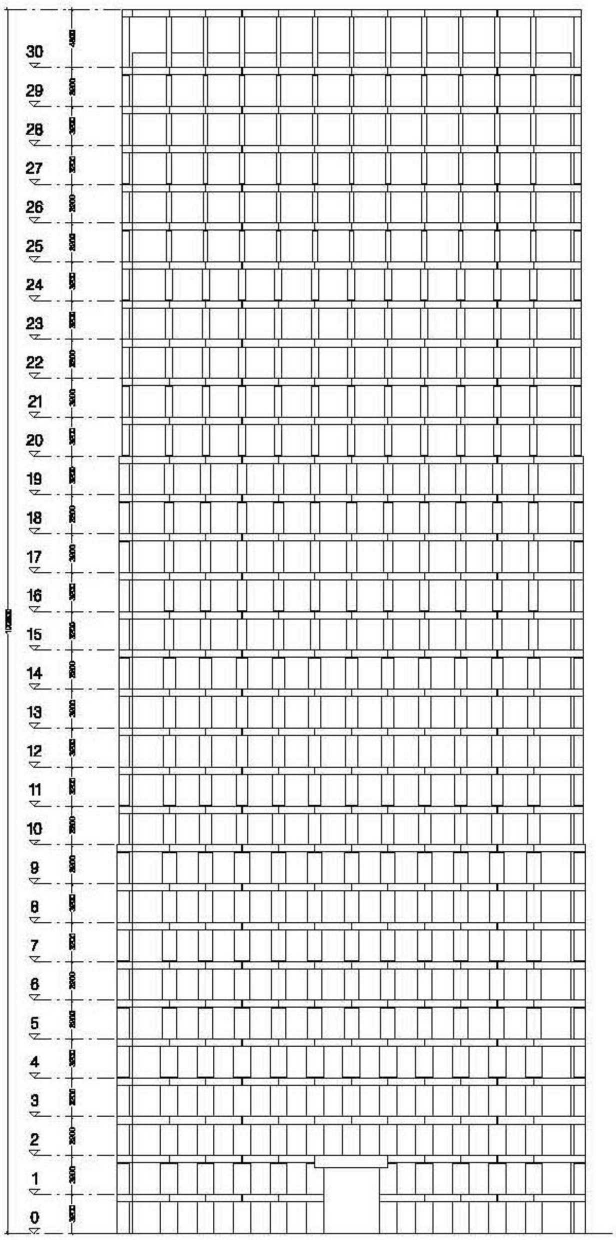
Construction Methodology – The Stonemasonry Company

Supplier - Polycor

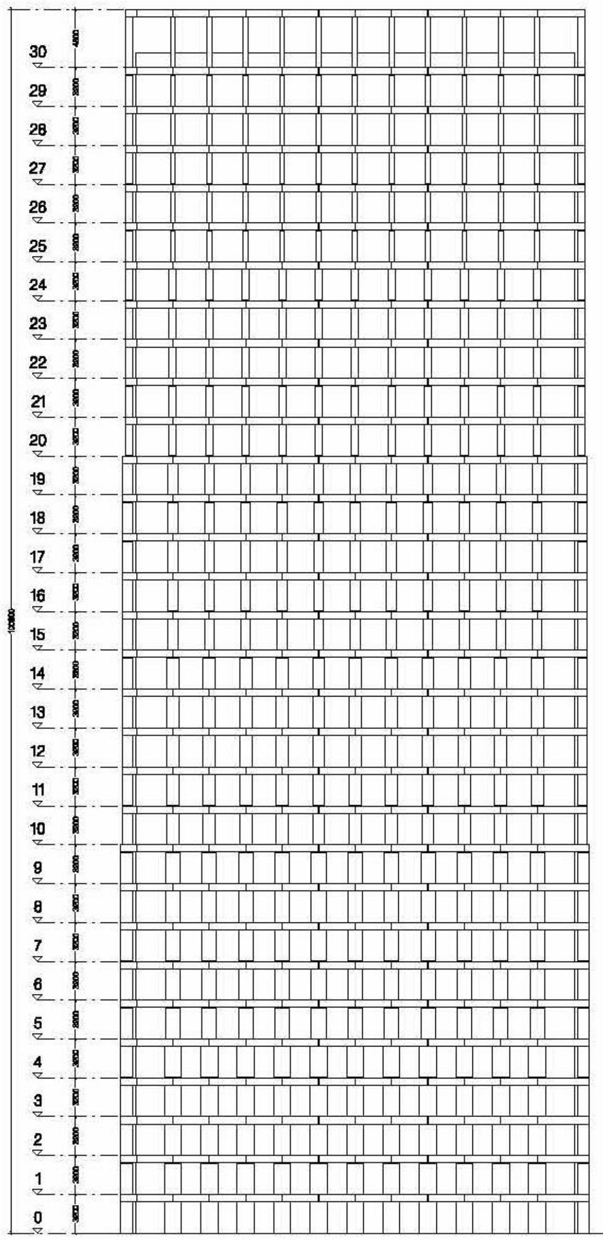
Architecture – Groupwork



Stone Tower – Typical Plan (stone flooring cassettes shown)



Stone Tower – Front Elevation



Stone Tower – Side Elevation

1.0 Summary

1.1 This paper looks at the comparative cost, programme and embodied CO2 for a notional commercial office tower. It has been assumed that the tower is 30 storeys with a total Gross Internal Floor area of 37,800 m^2 / 406,875 ft^2.

1.2 For comparison purposes the following structural solutions have been considered;

- Stone exoskeleton + Stone Cores + Floors
- Stone exoskeleton + CLT Cores + Floors
- Steel frame + Concrete Core + LW Steel/Concrete deck + concrete topping
- Concrete frame + Concrete Core + concrete topping

2.0 Purpose of Research

To investigate whether large scale commercial buildings can be built with stone superstructures, stone and or timber floor plates to meet the same criteria of optimum office space and building height as steel and concrete structures and be the same or lower in construction cost and carbon footprint?

3.0 Setting an Outline Brief for Commercial Office Space

Optimised Area Requirement; with the help of some of the UK's leading commercial space developers we asked for a brief that would optimise the ideal column free floor spans with internal flexibility for speculative office leased spaces? If they were to be achieved in one building the ideal net internal area per floor, ratio for gross to accommodate vertical circulation and amenities and in turn the optimum overall building area and therefore height? The 30 storey tower outline brief received, includes taller ground and rooftop levels for mechanical services split across roof and basement with the remainder of the roof for amenity space. 28 above ground floor are column free open plan office floor plates.

4.0 Method

4.1 **Exoskeleton Structure**- a stone exoskeleton is used for quicker erection on site and allowing a curtain wall to sit 200mm from it so that both weathering and thermal performance remains high without the need for window interfaces and thermal bridging points. In turn leaving the envelope as high performance and lower in cost.

4.2 **Stone and or CLT Floor slabs** – stone/post-tensioned 14m by 1.5m prefabricated floor slabs span from the central core to a perimeter ring beam connecting to the exoskeleton at one end. Alternatively, CLT spans in single planks to a ring beam picked up by the exo-skeleton.

4.3 **Central Core** – can be formed of stacked stones as there are no internal thermal criteria or CLT.

4.4 **Type of Stone** – granite or basalt can used for their ability to withstand and retain structural integrity in the event of a fire, availability, cost effectiveness, aesthetic and textural qualities.

4.5 **Fire Performance** - basalt was tested at the BRE fire testing facility during 2019 under the following conditions.

i. One side engaged with a thermal envelope and lined in plasterboard
ii. Two sides engaged with the thermal envelope and lined in plasterboard
iii. Disengaged column exposed to the elements as an exoskeleton and therefore exposed on all sides to fire.

Option iii performed best for longest reinforcing the exoskeleton as not only faster and cheaper to build with better weathering and thermal performance but also fire duration,

4.6 **Environmental Performance** – the distance of the exoskeleton from thermal envelope/ glazing line can be set by the latitude the building is to be developed as the beam line of the exoskeleton will act as a brise soleil cutting out the worst part of the summer sun but allowing it in the colder months, reducing energy consumption.

5.0 Conclusions

5.1 Cost

5.1.1 Inherently stone extraction, preparation, delivery and erection on site of an exoskeleton and core can be around 25% of that for a steel or concrete frame structure. Jackson Coles analysis of the market conditions with respect to availability of large-scale suppliers, installers and their relationship with respect ohpp to main contractors closes such savings. While the cost of the material and its erection on a 30 storey structure is estimated to be marginally greater than steel or concrete, it is the inherent finish of the stone which then saves considerably on the overall cost outcome as both steel and concrete would have to fireproofed, weathered, insulated then clad with stone veneers. These later processes adding capital cost and time on site while a load bearing stone exoskeleton is essentially already self-finished. Furthermore the glazing system / curtain wall sat behind the exoskeleton will not need to perform the same high level of "finish" function as the glazing and stone cladding system attached to a steel or concrete frame. As the exoskeleton also acts as a brise soleil the glazing performance can be lighter as can the MEP systems as less energy is required for cooling in summer.

5.1.2 Prefabricated pre-tensioned floor slabs – similarly, while the capital cost of a single plank is higher than a hollow core slab, the clean and level finish and density of the stone means no binding or screed topping is required. Saving on this cost, programme and load requirement of the building.

5.2 **Optimisation –** while placing the superstructure to the outside has multiple cost and thermal performance benefits it also allows for column free spaces within. However, the area and flexibility gained can be argued to have been placed at the perimeter of the wall. That is, if the building sits across 100% of the site boundary (not often permissible) then the exoskeletal and thermal envelope build-up have not gained extra internal area to lease but have at least allowed for clear column free floors.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5.3 Sustainability

5.3.1 Stone alone - inherently stone has zero carbon footprint. It is the energy used in quarrying, preparing and lifting the stone into place where CO2 builds up. Typically, if the quarry is in the same country then the stone superstructure will have saved 95% of the embodied CO2 against its steel or concrete equivalent. If the stone needs to be shipped in from abroad the saving may reduce to 80% or 70% for Europe and Asia/America respectively. If the stone is especially hard and deep within a quarry the saving will reduce to 60%. Even at 60% these are undoubtedly considerable savings which would far exceed the those expected of the industry as part of wider attempts to lower CO2 emissions.

5.3.2 Stone + CLT – As timber has carbon sequestration properties, combining stone as exo-skeletal superstructure and CLT floor plates and core will produce a CO2 negative building today. Again a far leap ahead of the carbon neutral ambition for the industry for thirsty to fifty years' time.

6.0 Appendices

Cost Comparison by Jackson Coles

Embodied CO2 by Eight Associates

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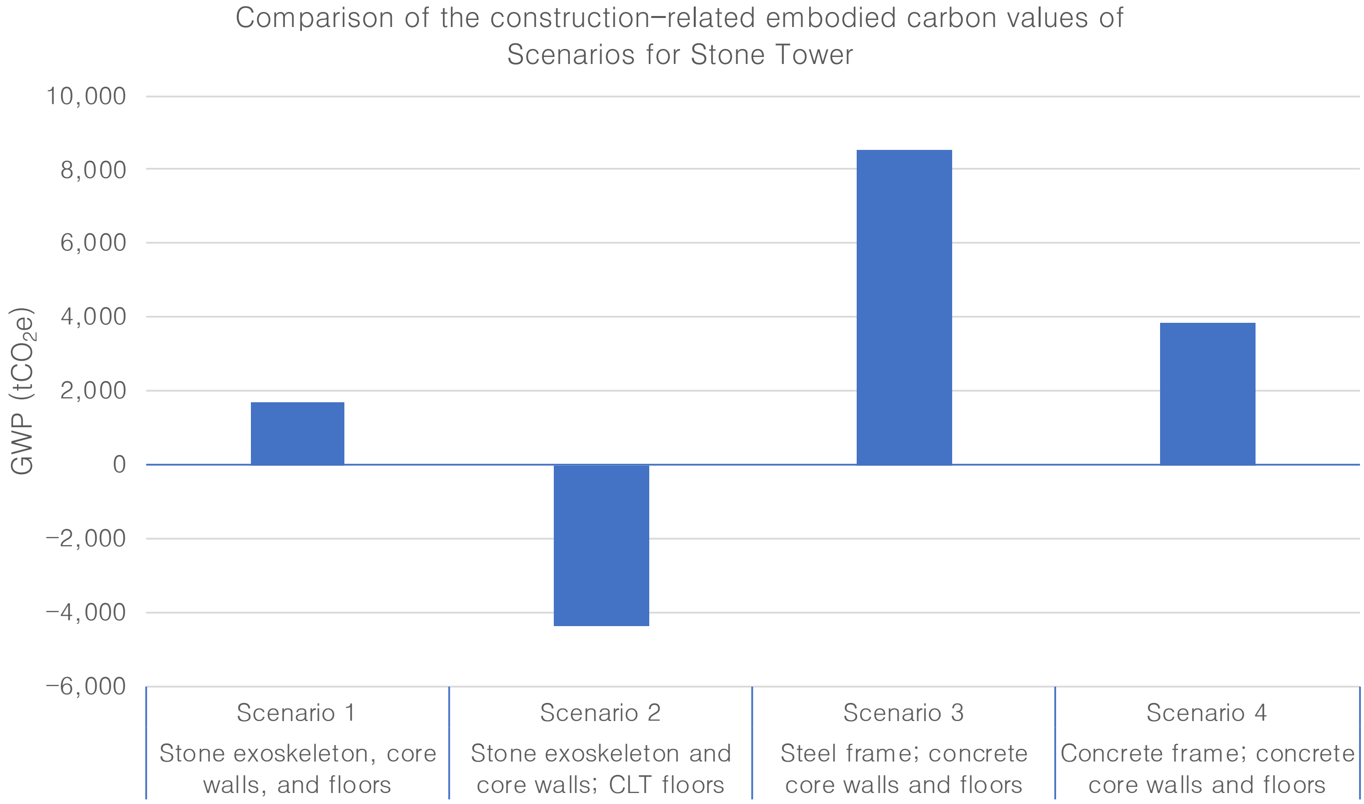
Summary
Embodied Carbon
Stone Tower

Summary

By specifying quarried stone to be used within the building, the embodied carbon from its inclusion are solely caused through the extraction, transportation, and installation. To have any additional processes such as polishing, etc, will result in a higher embodied carbon. It is possible that the specification of cross-laminated timber (CLT) will result in a much more favourable embodied carbon, due to the nature of timber sequestering carbon throughout its lifetime as a tree. In comparison, a building constructed primarily from quarried stone will result in a carbon reduction when compared to a concrete (approximately 60% reduction) or steel frame structure (approximately 80% reduction).

However, even this embodied carbon can be further improved on. The specification of CLT floors in place of stone floors will offset the embodied carbon of the entire original structure (stone exoskeleton, core walls, and floors), as well as a further 4,500 tCO_2e. This will allow for a greater chance of a wider berth of credits to be achieved for various certification bodies, resulting in an enhanced image of the development.



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Stone Tower Research Project

Indicative Cost Comparison (RevA)

Date: 20 February 2020

Job Reference: J007908

1.0 SUMMARY

1.1 This paper looks at the comparative costs for a notional commercial office tower. It has been assumed that the tower is 30 storeys with a total Gross Internal Floor area of 37,800 m² / 406,875 ft².

1.2 For comparison purposes the following structural solutions have been considered;

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- Concrete frame + Concrete Core + concrete topping

2.0 Frame and Upper Floors Cost Comparison

2.1 Stone Exoskeleton, Core+Floors *(stone "cladding" envelope already included)*

Description	**£**	**£/m² (Gross based on GIFA)**
Stone columns and beams; 5,282m³ @ £1,666/m³	£8.79m	£232/m²
Secondary steelwork; 5kg/m² based on GIA; 186t @ £3,000	£0.56m	£15/m²
Stone core walls; 4,850 m² @ £150/m²	£0.73m	£19/m²
Pre-tensioned stone floor planks (above ground); 37,800 m² @ £288/m²	£10.88m	£288/m²
Allowance for miscellaneous items; plinths; expansion joints; other structures; 37,230 m² @ £15/m²	£0.56m	£15/m²
Frame and Upper Floors Total	**£21.52m**	**£569/m²**

2.2 Stone Exoskeleton + CLT Core+CLT Floors *(stone "cladding" envelope already included)*

Description	£	£/m² (Gross based on GIFA)
Stone columns and beams; 5,282m³ @ £1,666/m³	£8.79m	£232/m²
Secondary steelwork; 5kg/m² based on GIA; 186t @ £3,000	£0.56m	£15/m²
CLT core walls; 4,850 m² @ £180/m²	£0.87m	£23/m²
CLT floor planks (above ground); 37,800 m² @ £200/m²	£7.56m	£200/m²
Allowance for miscellaneous items; plinths; expansion joints; other structures; 37,230 m² @ £15/m²	£0.56m	£15/m²
Frame and Upper Floors Total	**£18.34m**	**£485/m²**

2.3 Steel Frame only *(no stone "cladding" or envelope included)*

Description	£	£/m² (Gross based on GIFA)
Steel frame including fittings; 80kg/m² based on GIA; 2,978t @ £2,500/t	£7.45m	£200/m²
Secondary steelwork; 5kg/m² based on GIA; 186t @ £3,000	£0.56m	£15/m²
Fire protection; 3,164t @ £650/t	£2.06m	£55/m²
Reinforced concrete core walls; 4,850m² @ £350/m²	£1.70m	£46/m²
Lightweight concrete on steeldeck (above ground) 35,989 m² @ £120	£4.32m	£116/m²
Allowance for miscellaneous items; acoustics; waterproofing; plinths; expansion joints; other structures; 37,230 m² @ £20/m² *(increased to reflect greater requirement for above)*	£0.74m	£20/m²
Frame and Upper Floors Total	**£16.83m**	**£452/m²**

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2.4 Concrete Frame only *(no stone "cladding" or envelope included)*

Description	£	£/m² (Gross based on GIFA)
Insitu concrete columns and beams based on GIA; 37,230 m² @ £280/m²	£10.42m	£280/m²
Secondary steelwork; 5kg/m² based on GIA;186t @ £3,000	£0.56m	£15/m²
Reinforced concrete core walls; 4,850m² @ £350/m²	£1.70m	£46/m²
Pre-cast planks (above ground) 35,989m² @ £120	£4.32m	£116/m²
Allowance for miscellaneous items; waterproofing; plinths; expansion joints; other structures; 37,230m² @ £15/m²	£0.56	£15/m²
Frame and Upper Floors Total	**£17.56**	**£472/m²**

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3.0 Total Building

3.1 The below summary identifies indicative modelled costs for a simple open plan tower to CAT A. These costs are indicative only for comparative purposes and assume first quarter 2020 prices

with no inflation, risk or contingency allowances. The costs also exclude any Site Preparation or Basement works.

3.2 These cost allowances are notional only and will be subject to adjustment by size, shape, specification, site conditions, etc.

3.3 Preliminaries costs have been applied at a consistent percentage across the material types for comparison purposes. The impact of speed savings need to be established to determine impact on the preliminaries allowance.

3.4 The same Gross Internal Floor Area and External Envelope area have been assumed for all comparison studies.

3.5 On the façade, for modelling purposes, it has been assumed that the Steel and concrete solutions will be primarily higher quality façade system as they will need to act as the final planning approved face. The stone option reflects a lower curtain wall specification as it is behind the stone column and beam line specification and therefore able to utilise a glazing/opaque mix to reflect the existence of the exoskeleton.

3.6 For CAT A works, a lower cost has been applied to the Stone model. This is to reflect the reduced build-up prior to the suspended floor as no binding or levelling screeds would be needed for either stone or CLT floor plates due to the stone working as a level finish. Similarly, stone soffits can be left as exposed fair finish.

Element	Stone	Stone / Timber Floor	Steel	Concrete
Substructure[1]	£65/m²	£65/m2	£65/m²	£70/m²
Frame & Upper Floors	£569/m²	£485/m2	£452/m²	£472/m²
Roof, Stairs and External Walls[2]	£485/m²	485/m2	£565/m²	£565/m²
Internal Walls; Doors; Finishes and FF&E[3]	£250/m²	£250/m2	£295/m²	£295/m²
MEP Services[4]	£630/m²	£630/m2	£650/m²	£650/m²
CAT A Works (Indicative costs)	£300/m2	£300/m2	£360/m2	£360/m2
Preliminaries & OH&P @ 25%	£603/m2	£575/m2	£597/m2	£603/m2
Indicative Building Cost *(Based on GIFA)*	**£2,902/m2**	**£2,790/m2**	**£2,984/m2**	**£3,015/m2**

3.4 The Steel Construction Info website identifies a Total Building shell & Core cost (£/m2/GIFA) for Q4 2019 of £2,642/m2 for steel and £2,784/m2 for concrete. These include Basement works and Contingency allowances but exclude CAT A costs, so are comparable to the above when adjusted.

3.5 Spons 2020 identifies a cost of £2,962/m2 for a tower office development to CAT A. This includes basement works so is comparable when adjusted.

3.6 Stone budget costs for Frame and Upper Floors provided by Polycor and The Stonemasonry Company Ltd.

3.7 CLT budget costs for floors and core supplied by Eurban Ltd and Egoin Ltd.

1. *Assumes no Basement or significant site preparation works for modelling purposes*
2. *Stone façade reflects a saving as exoskeleton is the equivalent of the stone cladding on steel or concrete farmes allowing a reduction in specification requirements as cladding for steel and concrete will need fireproofing, weathering, insulating and galv/ss clamps to the stone veneers*
3. *Stone façade reflects a reduced sum on curtain wall finishes assuming the stone elements are the finish*
4. *Notional reduction on services to reflect potential savings due to the exoskeleton acting shading and therefore reducing further requirements, heat gain, etc*

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