

# Comparing the embodied energy of structural systems in parking garages

## an analysis of three built projects: cellular steel, precast concrete and post-tensioned concrete

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The structure of a typical office building contributes roughly one-quarter to one-third of the total embodied energy. Although the occupation phase of a building's life cycle currently dominates energy use, as operational energy use is minimized through high-performance design, construction and equipment, embodied energy will play a larger role in the overall energy consumption of a building. Consequently, the structural system should be a primary target for reducing the embodied energy of a building. Parking garages offer an ideal case study for comparing the embodied energy of a variety of structural systems. As above grade parking garages have little operational energy use outside of lighting and have few materials or systems beside the structure, the embodied energy of the structure comprises a majority of the environmental impacts during its life-cycle. By selecting existing parking garages built over the last 10 years of similar height and in the same seismic zone, the design loads, column lengths and structural layouts are fairly consistent, making more accurate comparisons between systems possible. Using material take-offs of three existing one-way structures, one pre-cast concrete, one post-tensioned concrete and one cellular steel, this study shows that there is little difference in the embodied energy of structural systems used for parking garages if steel with high-recycled content is used.

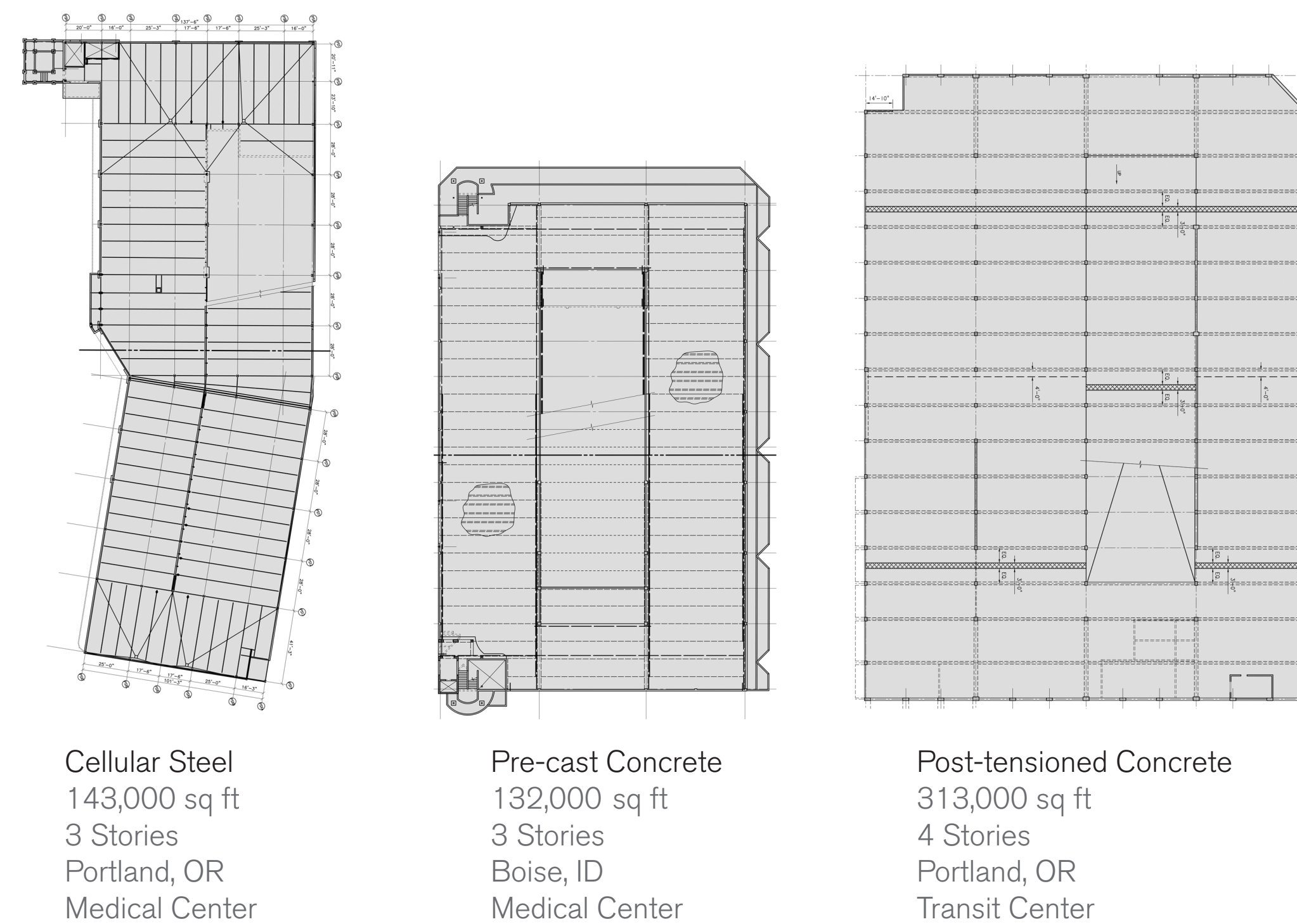
After spending a significant amount of time accounting for every structural component in each of the three case studies, the total amount of concrete and steel for each garage was normalized by the parking area of each structure. The precast concrete structure had the greatest amount of concrete per unit area and the cellular steel structure had the greatest amount of steel per unit area. The post-tensioned concrete garage came in the middle in terms of amount of concrete and has roughly half of the steel found in the cellular steel garage.

The amount of concrete in the precast garage is likely higher than it would normally be as it had the most cast-in-place concrete in the wall category, almost 14 pounds per square foot parking area, due to the depth of the first story below grade compared to the other two garages. The precast garage also had more concrete associated with the footings than the other two case studies. This is likely due to both the higher weight of the precast structure and the slightly weaker soil bearing pressure of this location. The amount of steel in the post-tensioned garage is greater than the precast structure due to the increased quantities of bar reinforcing in the post-tensioned slabs as well as its deeper and more reinforced slab on grade designed for bus parking.

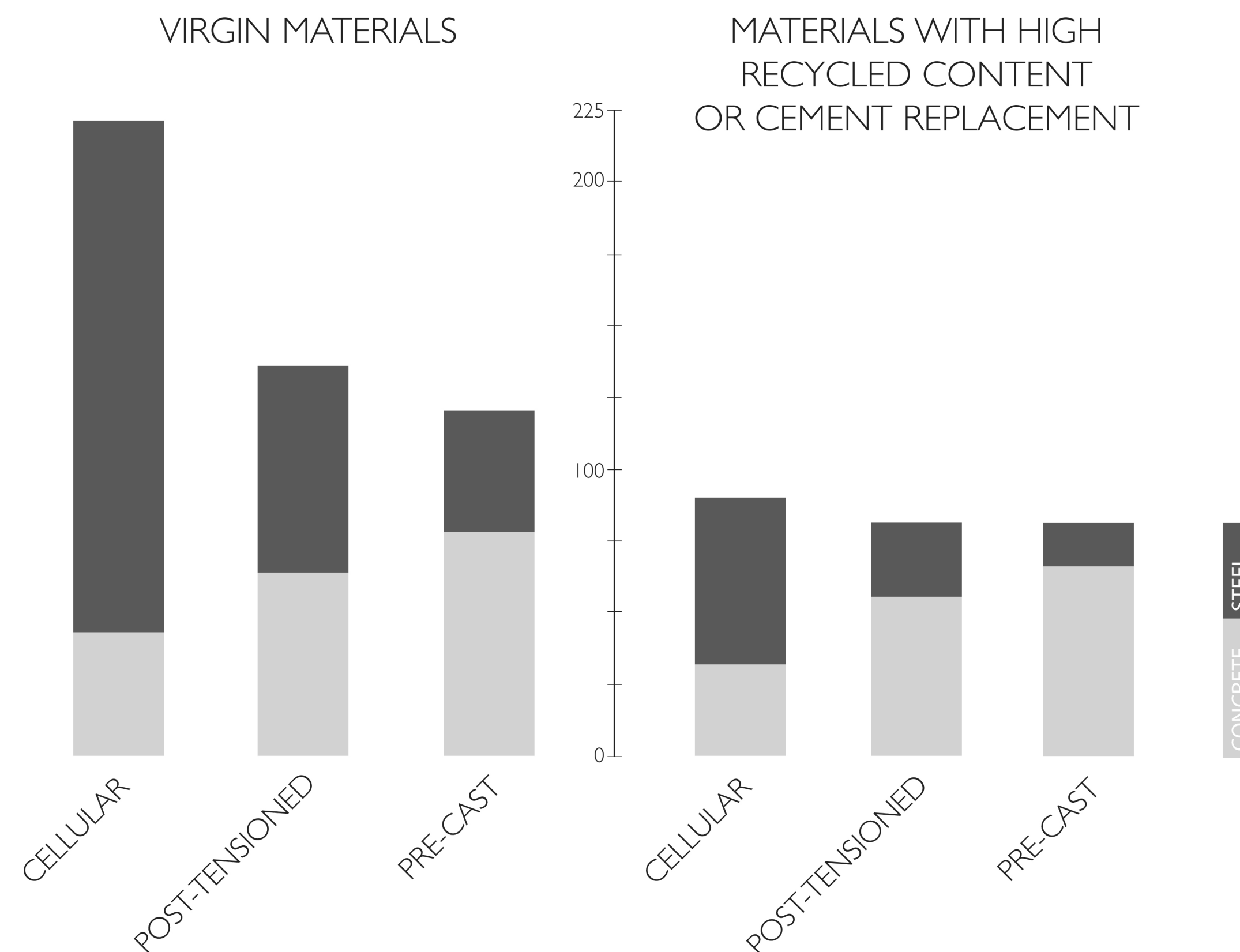
The total embodied energy for each parking garage was calculated based on the totals of each strength of concrete and type of steel used, once using values for virgin materi-

Table 1. Total "cradle-to-gate" embodied energy of each case study.

Primary Span	Area (ft <sup>2</sup> )	Virgin (TJ)	Cement Replacement (TJ) and Recycled Content	Reduction in Embodied Energy
Cellular Steel	143,000	30.8	12.7	59%
Precast Concrete	132,000	16.0	10.5	34%
Post-Tension Conc.	313,000	42.3	24.7	42%



### Embodied Energy per unit Area (MJ/ft<sup>2</sup>)



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als and once using values for the highest conceivable replacement of cement and recycled content in steel as discussed in Section 2.4 (Table 1). These two scenarios can create a range of embodied energy values that can be used to understand the trade-offs between using virgin and recycled materials. The greatest difference in embodied energy between the two material scenarios occurred in the cellular steel case study where there was a reduction of 59% using high volume fly ash concrete and high-recycled content steel.

While the post-tensioned concrete structure had the highest embodied energy overall, it is three times larger in terms of parking area than the other two case studies. To compare the relative sustainability of each structural system, the embodied energy was normalized by the parking area of each garage (Table 2). When comparing the structural systems using virgin materials, cellular steel is almost twice the embodied energy of either the two concrete structures. The zero recycled content steel accounts for 82% of the embodied energy in the cellular steel garage. The precast concrete and post-tensioned concrete structures are within ten percent of each other as the pre-cast structure uses less steel but more concrete and the post-tensioned structure uses less concrete but more steel. All three of the structural systems have roughly the same embodied energy, within 11% of one another, when using materials with high-recycled content and replacement of portland cement.

This study shows that there is little difference in the embodied energy of structural systems used for parking garages if steel with high-recycled content is used. In practice, it is far more likely to use high-recycled content steel than concrete with 50% replacement of portland cement with fly ash. This would negate the slight advantage the precast and post-tensioned concrete structural systems have. The most important step architects and engineers can take to reduce the embodied energy of a parking garage structures is to specify steel products with a high recycled content, specifically reinforcing bars and structural sections.

The authors propose a longitudinal study of the embodied energy of parking garages to verify the results of this sample and the development of tools for architects and engineers to more rapidly assess the environmental impact of these one-way structural systems. As the density of cities increases and new transportation infrastructure is built, parking garages will continue to provide opportunities to reduce the environmental impact of the built environment as well as insight into how structural systems in buildings of all types can be improved.

Table 2. Normalized "cradle-to-gate" embodied energy of each case study.

Primary Span	Virgin (MJ/ft <sup>2</sup> )*	Cement Replacement (MJ/ft <sup>2</sup> ) and Recycled Content
Cellular Steel	215	88
Precast Concrete	121	80
Post-Tension Conc.	135	79