To get to high performance, district energy systems that provide Lakeside with heating, cooling, and power are incorporated. Heating system will use biomass, sewage-heat-recovery, bio-gas, ground-sourced, solar. Cooling system will take cool water from Lake Michigan as either condenser water, or, direct chilled water pending on the temperature of the lake water intake and ground-sourced cooling energy. Power generation based on excess waste-heat in the district heating plant, wind turbines, rooftop solar PV for clean energy sources, and off-site sources: PV and wind farms, energy from inorganic waste. Due to the multiple phases of the development, energy generation facilities can be phased.

Individual building will be highly efficient. A standard Chicago home consumes twice as much electricity as one equipped with state-of-the-art, efficient and smart appliances and technologies. By designing for high-performance, optimal energy efficiency, and comfort, electricity demand in Lakeside will be significantly reduced. A Lakeside home will increase building efficiency: improved envelope, lighting, equipment and HVAC systems. The buildings will be connected to district systems and occupants will have smart controls for monitoring and feedback.

Optimization of Lakeside is not limited to the building level. When boundaries are lifted, individual system can expand to its optimal scale, some are at building level, for example, terminal units for heating and cooling, but others, similar to chilled and hot water plants are optimized at neighborhood scale. It is freedom for systems to go beyond boundaries that achieved the desired high performance development.

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Developing a Basis for Design—Embodied Carbon in Structures

M. Sarkisian, S.E., P.E.[1]; D. Shook, P.E.[2]; and J. Zhang, S.E., P.E.[3]

[1]Partner, Skidmore, Owings & Merrill LLP, San Francisco, CA.
[2]Associate, Skidmore, Owings & Merrill LLP, San Francisco, CA.
[3]Associate, Skidmore, Owings & Merrill LLP, San Francisco, CA.

Abstract

To date, most considerations for the impact of carbon emissions in the built environment directly relate to building operations. However, in most major projects it takes approximately 20 years of operational life before operational carbon exceeds the carbon embodied in the original construction. Minimum acceptance goals for implementation must then be created to encourage a responsible approach to environmental design—one that accounts for carbon emissions from groundbreaking through the building's service life. A tall building, at the time of construction, has a large impact on the environment through the production of building components, delivery, and construction as well as considering life-cycle in areas of abnormal loading (i.e., seismicity). SOM has developed an advanced algorithm called the Environmental Analysis Tool that evaluates embodied carbon as well as cost benefits of enhanced seismic force resisting systems in buildings and infrastructures. An evaluation of embodied carbon in over 200 built structures has revealed trends and correlations among common design parameters such as building height, occupancy type, seismic and wind conditions. This information can be utilized to set design goals and to provide standards for the reduction of embodied carbon through high performance seismic systems such as seismic isolation and pin-fuse devices, as well as ideas including Sustainable Form-Inclusion Systems (SFIS). Finally, an advanced parametric model has been created for new and existing urban developments. The Parametric City Model (PCM) will be used to illustrate the effects of material, construction, and urban density on the environment. Specific national and international tall building examples will be discussed. Buildings will include many of the tallest to date, including the Burj Khalifa, Dubai. These projects amongst others will be used as a basis to develop standards for design and construction for embodied carbon in structures. It is the hope that these requirements would eventually become standards for the industry.

INTRODUCTION

Designs for cities of the future need to be conceived through performance-based design. With decreasing material supplies and increasing demands, the cities of the future must use fewer natural resources while providing greater urban density and ultimately even the regeneration of resources. Decisions cognizant of the broader impacts on the environment and urban landscape need to be made early in the planning process through the conceptual design of districts, parcels, and buildings. Design must consider optimal net floor area efficiency, material use and resiliency to environmental disaster risks. Although efforts have been made at a broad level during planning stages, little effort has been made to accurately quantify performance at an individual parcel level at these early and influential phases. For example, municipalities can quantify fiscal and logistical impacts of increased height limits by allowing higher occupancy floor area ratios, but they do not typically account for potential impacts on net usable floor area (and associated fiscal performance) or the environment. To quantify these and other metrics of future cities, advanced algorithms have been assembled and are used within Parametric City Modeling™ (PCM). Criteria including parcel size, building shape, building height as well as primary structural material and abnormal loading demands such as seismicity can be varied to understand their individual and collective impacts. With only the parcel size and height limit known, the potential net usable floor area / commercial value and impacts on the environment can be evaluated. A brief summary of key algorithms follows:

Building Systems Modeling (BSM): This algorithm calculates building systems floor area, anticipated lease spans, and net floor area given only a parcel's plan extent and height. Building systems modeled include core program, structural system, elevators, stairs, and MEP shafts.

Environmental Analysis Tool™ (EA Tool™): This algorithm computes embodied carbon associated with structural systems.

In the future, other parameters such as shadow casting, day lighting, utility use such as water and electricity, embodied carbon of architectural and mechanical systems, and energy performance can be added with a weighting function to determine other optimal collective solutions.

Figure 1: Rendering of the Redeveloped Transbay District of San Francisco. Highlighted buildings indicate current and planned construction.

With knowing only parcel sizes and height limits, PCM has been applied to the Transbay District of San Francisco, California, to evaluate net usable floor area and embodied carbon of structures. With a significant number of parcels being redeveloped (Figure 1) the goal is to review impacts of the district as-planned as well as consider the impacts of taller height limits and variations of structural materials used for construction.

PARAMETRIC CITY MODELING

Parametric City Modeling™ is used at multiple scales including the city, the district, the parcel, and the building scale. The two key components of the methodology include Building Systems Modeling and the Environmental Analysis Tool™. In the following section these algorithms are described and have been based on calculations and hundreds of buildings designed over the last 40 years.

Building Systems Modeling (BSM)

The BSM algorithm facilitates an accurate and rapid estimation of building systems floor area requirements. With only the building form, seismic and wind conditions for the site, and structural material type, the floor area requirements of structural systems, elevator systems, corridor area, and area for stairs, mechanical, electrical, and plumbing systems are calculated. With this information a Net Floor Area (NFA) is determined by subtracting the area required for these items from the Gross Floor Area (GFA) at each floor of the building (Figure 2).

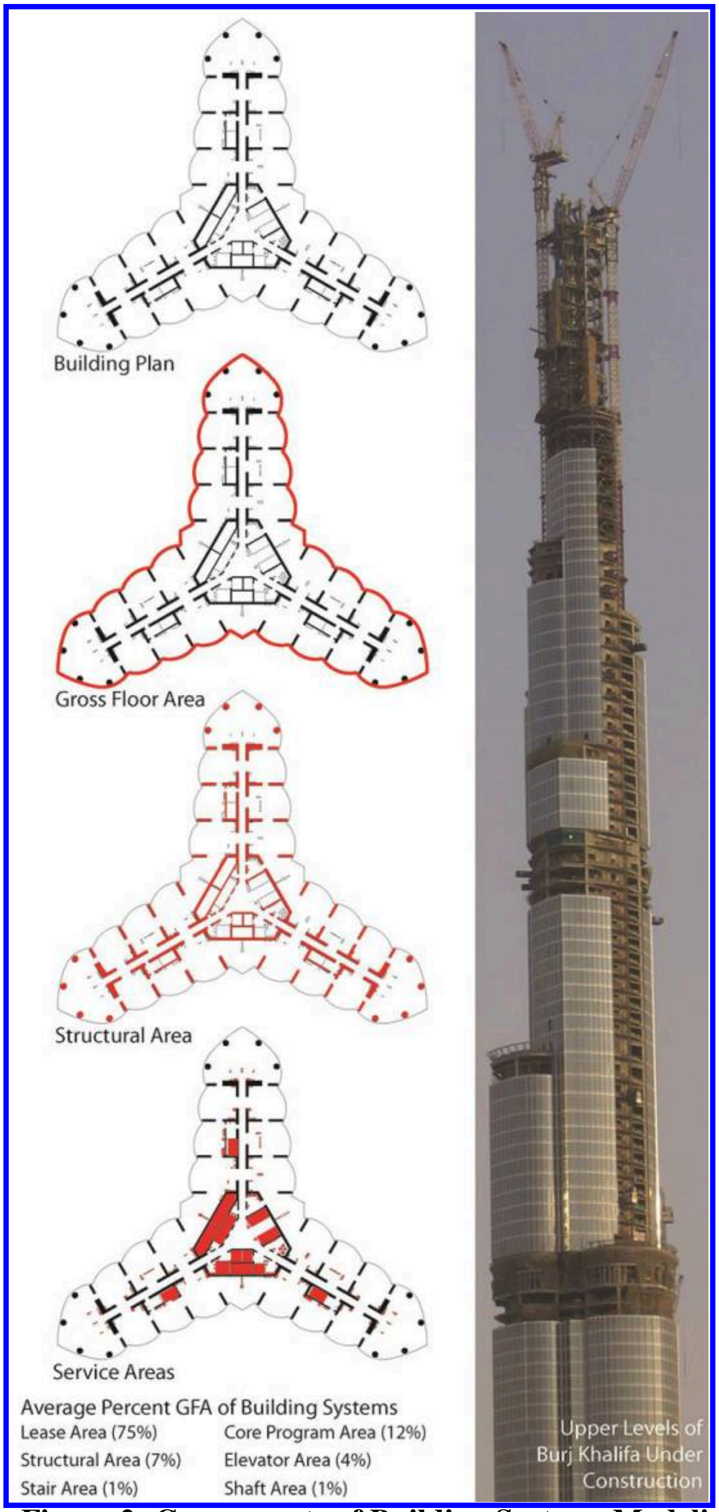
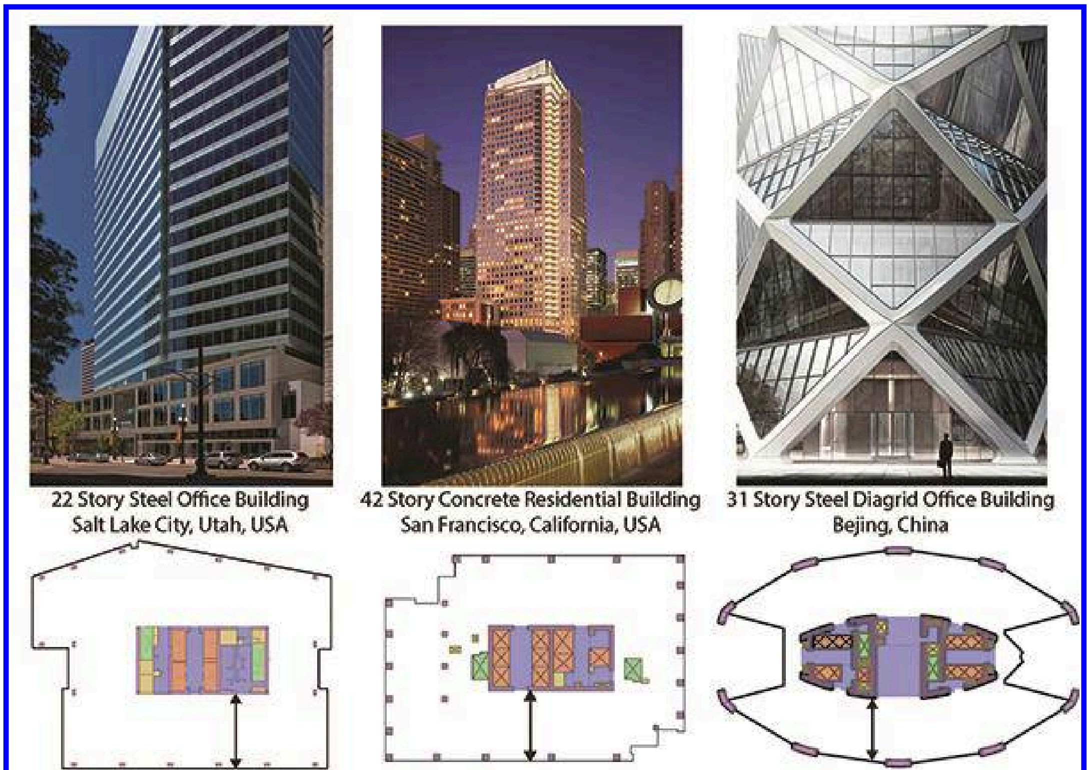


Figure 2: Components of Building Systems Modeling

Conditions which greatly influence the profitability, livability, and NFA are often set during planning stages with parcel sizes, height limitations, and other occupancy restrictions. Later, during more detailed design phases decisions which also affect space efficiency are often made in the conceptualization of a building form, before any detailed programmatic studies can be conducted. This lack of building-specific knowledge requires designers to use 'best guesses' as to what will make an efficient building. Using the PCM methodology, an early evaluation can be conducted in a parametric environment to quantify metrics and inform design decisions while they are being made. By quantifying these performance metrics early, informed decisions can be made.

Researchers and economists have concluded that a minimum NFA of 75% is typically required to make a tall building profitable (Yeang, 1995). Lower NFA values are common, many between 70-75% as documented for tall buildings constructed through the 1990's. Recently, developers have demanded NFA ratios of 80%, up to even 90%. These targets are increasingly challenging since the average height of newly constructed tall buildings continues to increase with proportional demand on building systems and consequently sizes of these systems (Sev et al, 2009). When building heights become significant (height > 200m), NFA efficiencies greater than 75% are even more difficult to achieve (Sev et al, 2009).



Metric	Actual	BSM	Actual	BSM	Actual	BSM
Net Floor Area	82%	82%	81.5%	80%	80%	83%
Core Program Area	8%	10%	8%	10%	10%	10%
Structural Area	4%	3%	4%	3%	4%	4%
Elevator Area	3%	3%	5%	5%	4%	1%
Stair Area	1%	1%	1%	1%	1%	1%
Shaft Area	2%	1%	0.5%	1%	1%	1%
Lease Span (m)	13.7	14.3	10.5	12	13.1	12.7

Figure 3: Floor Area Survey Examples

Building Systems: Using final design drawings, a floor area survey of several constructed buildings has revealed averages and trends among floor area usage of building systems. Results from three example buildings in this survey are reported in Figure 3 including building system floor area usage, NFA, and lease span. Furthermore, BSM is used to estimate the same metrics. As can be observed, the NFA and lease span calculations by BSM are reasonable estimations based solely on plan extents, building height and primary structural material.

A floor area survey of several buildings building systems has provided average values of key NFA components. On average, core area is 23% of. Composing this core area, building systems floor areas are, on average: 12% core program, 5% structural area, 4% elevator shaft area, 1% MEP shaft area, and 1% stair area. Core program consists of corridors, vestibules, lobbies, electrical and plumbing closets, janitorial, etc. The structural area is the plan extent of structural systems including enclosing finishes.

Structural Systems: Floor area required for structural elements such as columns, walls, and braces are estimated considering a self-weight of the structure based on material quantity estimation methods employed by the EA Tool™, assumed superimposed dead load of 0.7 kPa, and live load of 3.8 kPa. These are applied uniformly over the gross floor area and the total gravity weight is summed from top of building to base. This total load at the each floor is divided by the selected material yield strength. To account for additional material corresponding to the lateral force resisting system a factor is applied to the yield strength. For high seismic a factor of 0.25 is applied to the specified yield strength, whereas a factor of 0.4 is used for high wind. When wind or seismic is considered moderate, a factor of 0.5 is utilized. A minimum structural floor area of 3% is utilized.

Through this process a required plan area of structural material is determined considering the buildings form, height, material and subjected gravity and lateral loads. For steel, the plan extent of material is relatively small, but often steel shapes must be fireproofed and enclosed in finishes. As such, calculated structural steel floor area is multiplied by 10 to account for fireproofing and rectangular enclosure finishes.

Elevator Systems: Typically, a single cab elevator requires 9 m2 floor area. A tower under 45 stories will often have six to eight passenger elevators depending on the use, above 45 stories more extensive groups of elevators, up to 18, can occur at a single floor. In very tall buildings, elevator groups will stack and sky lobbies introduced every 45 floors. Groups of six elevators can serve approximately 15 floors each. If a group of 18 elevators occurred in a 45 story module of a tall tower, three groups of six passenger elevators would service 15 floors each. The elevators which service the lower 15-floor sections would stop at the top of their respective zones and that floor area would be utilized for increased NFA. Allowances for one service elevator and one sky lobby elevator per sky lobby are included.

Building Service Systems: Allowances are utilized for the core program (12%), shafts (1%) and stairs (1%) base on the building systems floor area survey. Future development of PCM will include adjustment to these values based on selected mechanical system type (central forced air common in office environments or local conditioning more comment in residential buildings).

Environmental Analysis Tool™

Most of the efforts to date made in calculating the carbon footprint of a building are associated with the operations of buildings with little or no focus on the structure at the time of construction and over its service life. The Environmental Analysis Tool™ calculates the expected embodied carbon of a structure at the time of construction considering its location and site conditions (Sarkisian et al, 2012; SOM, 2014). Based on the structural system considered, a damage assessment is performed based on the expected seismic conditions. Equivalent carbon dioxide emissions (CO2eq) associated with the structural system of a building may be categorized as those resulting from the following three major components: materials, construction, and seismic damage (Figure 4).

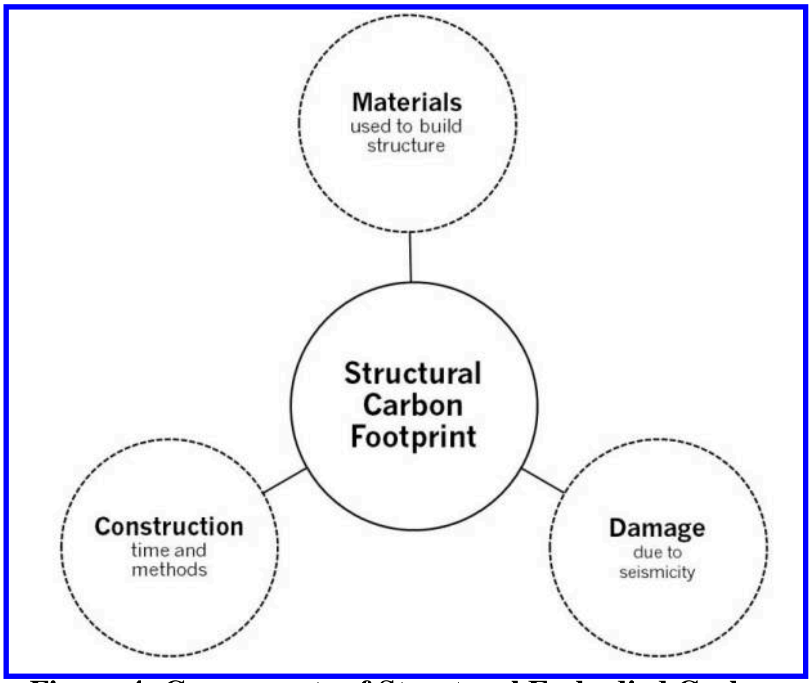


Figure 4: Components of Structural Embodied Carbon

It is important that the carbon footprint accounting is accurate even when limited information is available. The Environmental Analysis Tool™ (Figure 5) is capable of calculating a structure's carbon footprint with knowing only:

1. The number of stories (superstructure and basement).
2. The total framed area in the structure or average area per floor.
3. The structural system type.
4. The expected design life.
5. Site conditions related to expected wind and seismic forces.

With this small amount of information, the program refers to an algorithm developed from data mining of hundreds of built structures. This algorithm assists the designer when project-specific information, such as material quantities, is limited. Assumptions, such as crane operation and formwork durations, are based on field observations and practitioner experience is varied for different structural material systems. The goal of the algorithm, and corresponding software, is to be a design aid for the accounting of embodied carbon in structural systems. By considering the designs of the past we can inform the performance of our future cities.

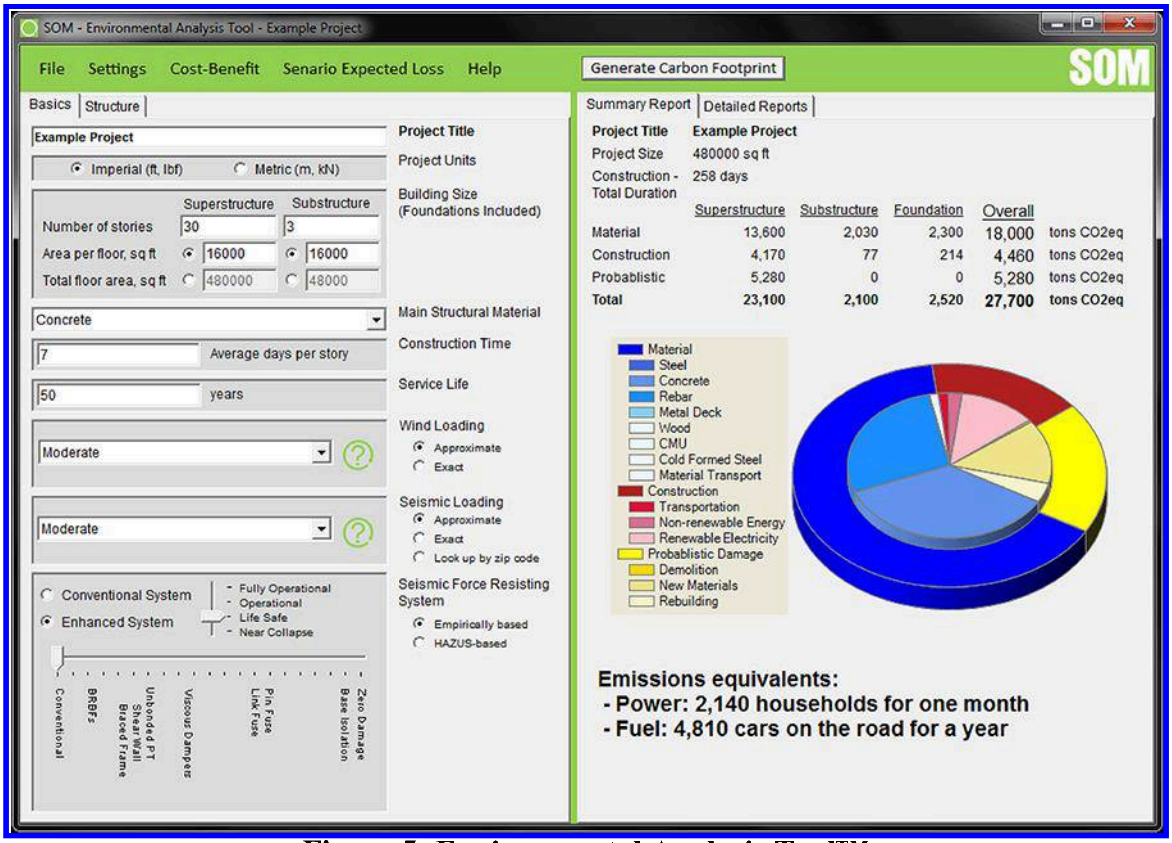


Figure 5: Environmental Analysis Tool™

The EA Tool™ has been used on multiple projects for critical design decisions, often resulting into either significant consideration or adoption of carbon mitigating measures such as enhanced seismic performance. A residential development of two towers in San Francisco, California, is considerate where carbon impacts and financial performance of a base isolated scheme were evaluated and conveyed to the client for an informed decision that lead to the inclusion of base isolation into the design of the buildings (Figure 6).

The EA Tool™ has been made available for free to the public to provide engineers, architects, owners, and contractors the means to evaluate embodied carbon (SOM, 2014). The ultimate goal is to enable the quantification of embodied carbon in structures which ultimately leads to a discourse across the profession and adds to a conversation already happening world-wide regarding the sustainability of the built environment.

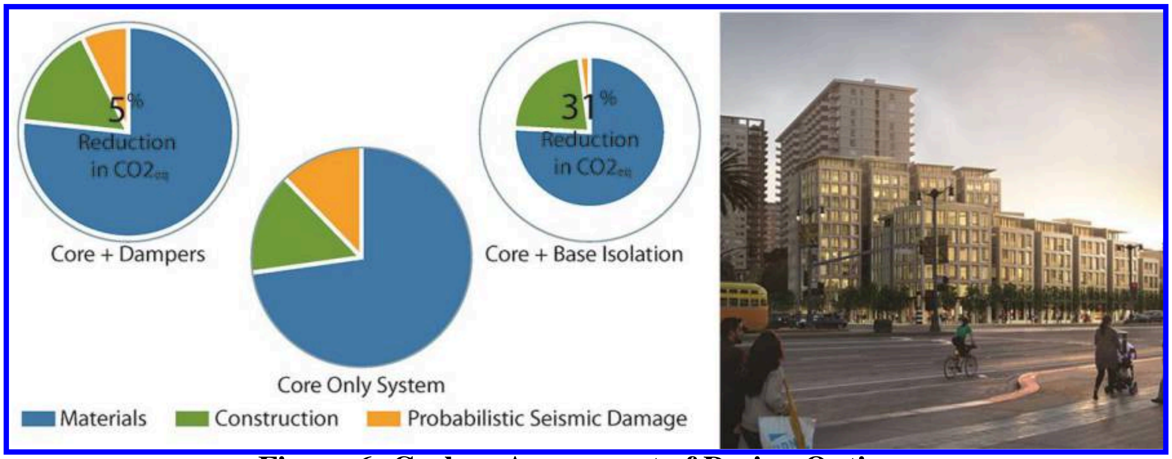


Figure 6: Carbon Assessment of Design Options

DATA + EMBODIED CARBON

As discussed previously by the authors, a survey of built or fully designed buildings has been conducted to quantify floor area requirements of major building systems such as structure, elevators, stairs, mechanical, etc. Additionally, other building characteristics such as height, form, embodied carbon, and NFA are considered. These data are compiled and studied for trends and correlations (Sarkisian and Shook, 2014). Figure 7 presents correlations among studied building characteristics.

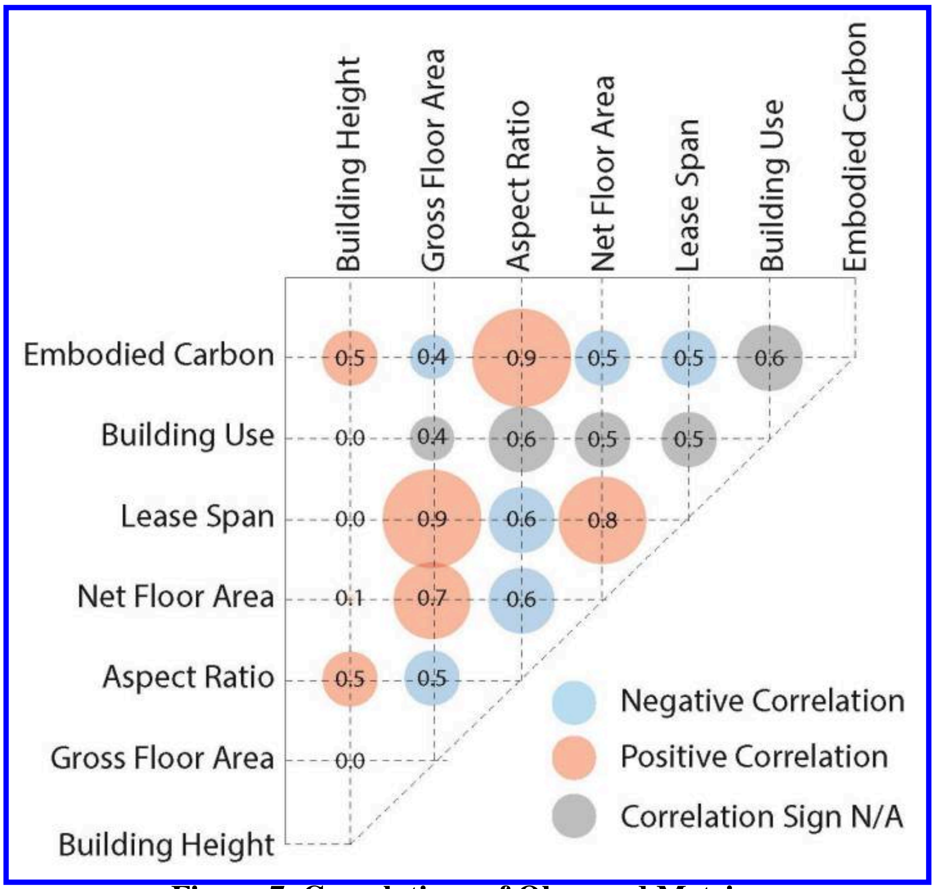


Figure 7. Correlations of Observed Metrics

Also, using this information a series of carbon benchmarks have been developed and used for understanding embodied carbon levels (Sarkisian and Shook, 2014) as shown in Table 1. These goals are envisioned to help form the basis for incentive-based system and future codification. They has also been used in the current study as a benchmark for embodied carbon levels.