the capacity of bachelor-level architecture students to grasp the concepts of adaptive design and to implement those concepts into design projects through the use of physical computing and parametric modeling platforms.

While the integration of adaptive systems into architecture holds great potential in relation to environmental performance, user satisfaction, and aesthetic possibility, it remains an area of architecture that is largely unexplored. The reason for this may be the steep learning curve of its interdisciplinary nature. However, as an increasing number of architecture students and practitioners are exposed to these concepts and techniques, they are bound to become the catalysts of which Peak writes, and before long, adaptive architecture will be commonplace in our built environment.

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REFERENCES


1 INTRODUCTION

Design is in a constant state of change. Ideas that are just a few years old are left at the wayside for trends that are influenced by turbulent markets, new technology, and an evolving society. With these changing times, designers are exploring new urban fabrics and forms. Often these challenges lead to new ideas and spaces, which introduce an element of novelty and uncertainty to design. Guidance is needed at early design stages through metrics to inform decisions and reveal potential synergies.

Data is not a static entity, but a dynamic resource. The potential flow of information in today’s society is just beginning to be realized. Information can be moved, refined, and reformatted into new life. This resource is renewable, sustainable, and uniquely reflective of our society. Unlike traditional resources, which are consumed and forgotten, information can be processed for predictive patterns of our future activities.

A recent example of data mining of a built environment is the development of the San Francisco digital context model developed by Skidmore, Owings & Merrill LLP (SOM 2010). Physical and digital information about San Francisco buildings including height and form, soil conditions, construction data, census information, and other environmental variables are contained in the model. With compiled information about existing and planned buildings, digital context can inform design in ways not previously realized.

For the current effort, authors have collected information pertaining to the built environment by observation of previously designed buildings from a variety of regions around the world. Data such as gross floor area, number of stories, occupancy use, material type, geographic location, seismicity, and climatic influences have been harvested. This information is processed for recognition of patterns to determine key attributes that most affect the built environment as it relates to sustainability and floor area efficiency.

The Environmental Analysis Tool™ (EA Tool) computes equivalent carbon dioxide emissions for structural components of buildings. The design tool considers a variety of building and material types, probabilistic damage, and construction methods. With EA Tool, factors beyond traditional metrics such as LEED can be considered for holistic approaches to sustainability.

The Parametric City Modeling (PCM) tool computes net floor area efficiency of each floor of a building by estimating required floor areas of key components such as structure, elevator, mechanical, electrical, and plumbing. This can be done when only form and other parameters typically known at the onset of design are defined. Key design factors such as saleable area, profitability, shadow effects, and building orientation can also be incorporated with PCM.

Environmental impacts of structural systems need to be considered equally to available materials, constructability, and cost at the earliest stages of design. It is important that the carbon footprint assessment is accurate even with a limited amount of known information. The EA Tool is capable of calculating the structural system’s carbon footprint knowing only:

- The number of stories (superstructure and basement)
- The total framed area in the structure or average area per floor
- The construction system type
- The expected design life
- Geographic conditions related to expected wind and seismic forces

With this limited amount of data, the program refers to a comprehensive database containing the material quantities for hundreds of previously designed buildings. Statistical models and curve-fitting techniques are used to consider building height relative to low, moderate, or high wind and seismic conditions. Superstructure materials include structural steel, reinforced concrete, composite (combination of steel and concrete), wood, masonry, and light metal framing. Foundation materials include reinforced concrete for spread/continuous footings, mats, and pile-supported mats. Key concepts of the EA Tool are presented in Figure 2.

The selected seismic resisting system is important to the carbon footprint over the life of the structure. The contribution of carbon related to damage from a seismic event could account for 25 percent or more of the total carbon footprint for the structure. If the building is only designed to code-minimum standards, then the building may need to be completely demolished after a design-basis earthquake. Conventional code-based structural systems are provided with the option to select

These tools evaluate the performance of buildings based on patterns abstracted from harvested data. It is envisioned that these tools can serve as guides to sustainable and efficient buildings to address an ever-changing design climate. In a predictive manner, which relies upon already realized structures, performance of new forms can be evaluated across a variety of metrics.

Synergies of embodied carbon, material, form, wind, seismicity, circulation, profitability, orientation, etc. can be incorporated into the fabric of the built environment at early design stages. These tools can aid designers in addressing the ever-changing design environment of today and challenges of tomorrow.

2 CARBON METRICS

Environmental impacts of structural systems need to be considered equally to available materials, constructability, and cost at the earliest stages of design. It is important that the carbon footprint assessment is accurate even with a limited amount of known information. The EA Tool is capable of calculating the structural system’s carbon footprint knowing only:

- The number of stories (superstructure and basement)
- The total framed area in the structure or average area per floor
- The construction system type
- The expected design life
- Geographic conditions related to expected wind and seismic forces
enhanced systems such as seismic isolation, unbonded braces, viscous damping, and Pin-Fuse Seismic Systems™ (Figure 7). Potential seismic damage and the repair required are considered.

The program uses this fundamental information to estimate construction methods and duration, fabrication and transportation of material, labor required to build the structure, and laborers’ transportation needs, among others. With this limited amount of information, an early but accurate assessment of the structure’s carbon footprint can be performed. Program interface examples are shown in Figures 3 and 6.

2.1 Conventional Versus Enhanced Seismic Systems

The engineering community has made significant advancements in the design of structures in regions of high seismic risk, but most developments have been focused on life safety with only modest focus on performance or long-term economic viability. Little focus has been directed to the environmental impact of these structures. Structures that naturally coexist with their site conditions produce the most efficient designs, produce the most cost-effective long-term solutions, and have the least impact on the environment.

Imagine structures with minimal materials used that exhibit minimal damage even when subjected to the most extreme seismic events. Imagine these structures are designed based on natural behavior principles rather than conventional approaches to design. Improvements were made to steel beam-column moment connections following the nondurable performance of many frames in the 1994 Northridge, CA, earthquakes. Other systems, such as the RRS (Reinforced Steel System) shown in Figure 6. The RRS used a refined beam section or “diaphragm” connection and the split web connection were developed. However, these systems and others deform permanently during major earthquakes to dissipate energy. Designers must develop systems that dissipate energy, deform with minimal damage, and allow the building to be placed immediately back into service after the earthquake.

Allowing controlled movement with the dissipation of energy in structures during earthquakes is important. This movement can occur at the structure’s base or within the superstructure itself. Seismic isolation (Figure 5) is an excellent solution to decoupling structures from strong ground motions. When structures are fixed to their foundations, rotational movement must be designed to occur within the joints of the superstructure. Pin-Fuse Seismic Systems™ (Figures 6 and 7) are designed to maintain joint flexibility throughout the typical service life of the structure. When a significant seismic event occurs, forces within the frame cause slip in joints through friction-type connections. This slippage alters the characteristics of the structure, lengthens the structure’s fundamental period, reduces the forces attracted from the ground, and provides energy dissipation without permanent deformation. After the seismic event the bolts can be reattached and the structural frame restored since no permanent deformations have occurred. This level of disaster resiliency is vital to building structures sustainably in seismically afflicted regions.

2.2 Reduction of Seismic Mass

The most efficient and environmentally responsible structures are those with the least mass and those that incorporate structural components informed by nature. Reducing seismic mass can be accomplished with the use of lightweight materials such as lightweight concrete, which has 25 percent less mass than normal-weight concrete. Other concepts can be introduced that further reduce mass. In all concrete structures there are areas that include significant amounts of concrete only because of conventional construction practices. For instance, the amount of concrete needed in the middle-middle strip of a two-way reinforced concrete floor-framing system could be reduced by 30 percent or more by introducing more scientific systems. If concrete in these areas is displaced where it is not required, this reduction could be achieved. A form-inclusion system, perhaps one that includes post-consumer waste products that cannot be recycled or downcycled to other products, could be used. This innovative construction method can be incorporated into EA Tool analysis by incorporating conventional methods of construction.

3 Efficiency Metrics

Efficiency is a metric that quantifies the use of space. Numerous factors influence the efficiency of space in a building, such as required gross floor area (GFA), programmatic requirements, budget, client intent, architectural design intent, availability and cost of materials, sustainability goals, performance requirements of structural, mechanical, plumbing, and electric systems, geographic and climatic disposition, and intelligence of employed technologies. Optimal design is achieved when salient factors achieve an equilibrium that satisfies all components. Figure 9 outlines factors that affect optimal design. Some characteristics are readily quantified; other traits are more qualitative and can be difficult to evaluate with a numerical metric.

NFI area is a metric that can be used to describe usable floor area, as defined in a percentage of gross floor area remaining after subtracting all structural and service components. This area is habitable and often leased to tenants by the building owner.

Structural components that directly affect NFA include columns, walls, and beams. Service components that directly affect NFA include elevators, mechanical equipment, plumbing, electrical, etc. These concepts are described in Figure 8. This simplification of the broader scope that influences building efficiency (Figure 9) is considered to focus on quantifiable metrics of building efficiency, which could be used on any project. Project-specific factors such as client or design intent could be incorporated on a case-by-case basis.

Figure 3
EA Tool user interface.

Figure 4
EA Tool™ cost-benefit application.

Figure 5
Base isolation (triple friction pendulum isolator shown).

Figure 6
Pin-Fuse Joint™.

Figure 7
Pin-Fuse Seismic Systems™.

Figure 8
(a) Polyurethane, (b) SFIS seat, (c) SFIS incorporated into structural slabs.
Parametric City Modeling (PCM) is a novel approach to design that relies on harvested information from previous SOM-designed buildings to inform current design. This is done in a robust manner that can be employed when only the perimeter form of the building is known. When implemented in a parametric environment, PCM provides a rapid estimation of building efficiency (NFA) with estimations of required area for structural and service components (see Figure 12).

Numerous previously designed projects are studied to obtain a database that describes parameters such as GFA, area occupied by structural elements including columns, walls, and braces; area occupied by mechanical, electrical, and plumbing equipment and risers; area occupied by vertical transportation such as elevators and stairs; and so on. These values are obtained at several floors over the height of each building to obtain a gradient of performance information. Harvested data is mined for numerical relationships that describe key structural and service components as a function of building height. With these relationships, predictions of building efficiency can be obtained and used for informed design decisions.

3.3 Structural Component Estimation

Area required for structural elements such as columns, walls, and braces are estimated based on parameters such as building height, floor area, assumed gravity loads, material employed, seismicity, climatic influences such as wind loads, and overall building aspect ratio. Initial material quantity estimation occurs using the quantity estimation algorithm employed for the EA Tool. With assumptions for gravity loads, total weight of the building can be estimated. With the specified structural material type, a total estimate of area required for structural components can be obtained. These results are also adjusted based on building aspect ratio. Estimations for these components are made at every floor of the building.
3.4 Service Component Estimation

Based on harvested data, trend lines are obtained for areas required for service components including elevators, stairs, mechanical, electrical, and plumbing as a function of total building height. Current mechanical, electrical, and plumbing allowances are lumped together, but future development could break these components apart for more responsive estimations. Estimations for these components are made for the low-, mid-, and high-rise portions of the building.

4 PARAMETRIC INTEGRATION

The EA Tool is combined with PCM in a parametric environment (Grasshopper 2012) that is responsive to building height, aspect ratio, form, material, and location. Estimations of structural components, service components, and NFA can be conducted for any form generated in the parametric environment. Recently, this tool has been applied to an urban planning study for an ultra-high-density development in Shenzhen, China, consisting of 130 buildings containing numerous high-rise residential and office towers (Figure 13).

Efficiency and carbon analysis results reveal low lease efficiencies and disproportionately high levels of embodied carbon in several tall towers as shown in Figure 13. Here, darker areas indicate unfavorable efficiency and lighter areas indicate favorable efficiency. The initially proposed centerpiece twin towers in the Shenzhen urban planning study are an example of towers where building depth at the base of the building needed to achieve desired structural performance resulted in lease spans that are too deep by industry standards. Recently proposed tall towers responded to this condition by introducing sky gardens at the perimeter of the tower to reduce lease spans between core and exterior to more desirable levels while maintaining the necessary structural depth. Although gardens make for interesting spaces, they are generally not considered an efficient use of space or materials.

With this context, designers proposed a coupled-core structural system that utilized synergy in structural and elevator efficiencies through sky bridges that act as major linkages. This concept is illustrated in Figure 14. The effective depth of a single slender tower can be greatly increased when coupled with neighboring towers to increase the effective depth of the coupled structural systems. Furthermore, elevator efficiencies are realized by condensing the sky lobby elevators into a single tower and connecting them to the adjoining towers with sky bridges. This change in lease space efficiency can be clearly seen in Figure 13, where darker areas are greatly reduced in the coupled-core tower scheme compared to the twin tower scheme.

5 PLANNING FOR CITIES OF THE FUTURE

Master planning efforts have greatly improved the flow of modern cities and facilitated guidelines for urban growth when compared to previous decades, but they only consider factors immediately relevant to developers and municipalities. Yet the impacts of these decisions have far-reaching effects that are generally not considered until later stages of design development. Harvesting existing built-environment information for the generation of predictive tools facilitates the consideration of these factors at early design stages. Influences such as climate effects of carbon, relative building locations and orientations, building materials and their sources, wind-mitigating measures, probabilistic seismic damage, and life-cycle assessments could guide design toward intelligent design.
CONCLUSIONS

Two innovative tools used for the quantification of building efficiency and sustainability are presented. These performance tools rapidly evaluate building performance with regard to floor area efficiency and equivalent carbon footprint when only the perimeter form of the building is known.

With increasing complexity and efficiency requirements of tall buildings, innovative platforms must be developed that rapidly inform designers during initial stages of development. It is envisioned that the EA Tool and PCM could guide designers toward synergy-oriented design of new urban centers and rehabilitation of existing districts.

Expanding traditional metrics of design at planning stages to include embodied carbon emissions, salable area, climatic influences, probabilistic seismic damage, and construction materials facilitates a holistic approach to design. Multi-objective optimization routines could be implemented for investigation of concurrent performance of competing design objectives. Such implementations would facilitate a new generation of sustainable design, where efforts of the past begin to inform advancements of the future.

REFERENCES


CONDITIONING ELEGANCE:
A DESIGN EXPERIMENT ON INTUITION AND ANALYSIS

ABSTRACT

This paper offers an assessment of two methods for design—one based on intuitive design skills, the other on feedback from performance analysis—offered within a course with a biomorphic focus. The project demands a design solution that operates on two levels, function and aesthetics; students focused on proposing an “elegant” building component without compromising structural efficiency. The results are discussed with regard to aesthetic theory, as indicators toward integrating analysis tools in creative processes and also understanding different learning paradigms for students. Furthermore, the students’ perception of the process within two different rule-based systems is discussed. Finally, the evolution of this experiment within a clinical framework by collaborating with neuroscientists is contemplated, with the scope of collecting quantifiable data about aesthetics and establishing a connection with data-driven design processes.

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