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Title:	**Securing the Vibrant Future of our Cities: Decision Making Principles for Aspirational Projects**
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Subjects:	Architectural/Design Building Case Study Structural Engineering
Keywords:	Concrete Design Process Integrated Design Performance Based Design Structure Technology
Publication Date:	2015
Original Publication:	Global Interchanges: Resurgence of the Skyscraper City
Paper Type:	1. Book chapter/Part chapter 2. Journal paper 3. **Conference proceeding** 4. Unpublished conference paper 5. Magazine article 6. Unpublished

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Securing the Vibrant Future of our Cities: Decision Making Principles for Aspirational Projects

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Abstract

There is a tension between aspirations and risks in the development and delivery of any building project. Columbia University Medical and Graduate Education Building (CUMGEB) was designed to revitalize Columbia's Washington Heights campus by creating an identity that "represents the highest aspirations of medical education". With noble qualitative goals such as this, CUMGEB's ambitious design presented the project team with several challenges, yet the risks were mitigated and the constructed building remains remarkably unchanged from the original design intent. This paper strengthens the collaborative dialogue between stakeholders pursuing the vibrant future of cities by establishing six critical principles for a design and management process that endeavors to achieve high qualitative goals by mitigating quantitative risks. A broad and holistic viewpoint on project decision making is presented with commentary offered on these six principles from the perspective of a structural engineer.

Keywords: Concrete - Post-tensioned; Design Process; Integrated Design; Performance Based Design; Structure; Technology

There is a tension between aspirations and risks in the development and delivery of any building project. Goals rooted in our transformative aspirations for the built environment can be difficult to measure, while technical challenges and risks are often quantifiable, and because our decision making process generally gives more weight to outcomes that are tangible (through an assortment of cognitive biases), there is a tendency to pursue designs and solutions that minimize risk in such a way that inadvertently marginalizes our more abstract ambitions.

By purposefully refining the tools and environment for decision making, all builders - owners, developers, designers, and contractors – can advance the design and management process by which projects are developed and delivered, thereby positioning project teams to successfully fulfill upon their comprehensive ambitions while overcoming delivery challenges and mitigating risks. In doing so, builders can contribute to securing the vibrant futures of our cities during this ongoing economic rebound and world-wide resurgence of construction.

This paper identifies six critical principles for a design and management process that endeavors to achieve high qualitative goals by mitigating quantitative risks. At the heart, these six principles combine to create a project delivery environment where risks can be confidently managed and resolved, allowing project stakeholders to holistically pursue their ambitions. This paper is not intended to define good or inspirational design, but rather is intended to assist readers in delivering a project compatible with their own values.

To demonstrate these six principles and their impact on the successful fulfillment of the project team's aspirations, the Columbia University Medical and Graduate Education Building (CUMGEB) is examined (see Figure 1). CUMGEB was designed to revitalize Columbia University's Washington Heights campus by creating an identity that "represents the highest aspirations of medical education". With noble qualitative goals such as this, CUMGEB's ambitious design presented the project delivery team with several challenges, yet the risks were mitigated and the constructed building remains remarkably true to the original design intent.

This paper is intended to strengthen the collaborative dialogue between project stakeholders that are pursuing the vibrant future of our cities. A broad and holistic viewpoint on project decision making is presented with commentary offered on these six principles from the perspective of a structural engineer. Because of CUMGEB's varied spatial planning in which the building's form expresses the function of the design, successful delivery of an architecturally-integrated super structure is vital to the overall achievement of the stakeholder's comprehensive aspirations for this project.

Six Principles for Achieving Projects with High Stakeholder Aspirations

Six critical principles for a design and management process that creates a project delivery environment in which risks can be managed and resolved in order to achieve high qualitative goals are as follows:

1. Engage in an early and active dialogue between stakeholders

A collaborative environment established through an active dialogue between all stakeholders where the exchange of ideas pertaining to options and criteria are identified and addressed by relevant parties as early as possible, is an effective way to establish the foundation of trust that is required to work through the myriad of challenges that arise when delivering projects with broad aspirations.

Creating this collaborative environment and active dialogue often involves the establishment of a core project delivery team from the start of a project. This dialogue is most effective when it is ongoing, balancing aspirations and identifiable benchmarks, acknowledging that early, vetted decisions can have maximum positive impact on the project.

2. Identify performance based systems and establish criteria

Utilizing the aforementioned active dialogue, identification of systems to which performance based design principles can be applied, and the establishment of corresponding performance criteria, is an advantageous decision-making method that allows for objective comparison between systems and enables the simultaneous achievement of design intent and effective performance.

Such performance-based systems can be fully investigated and parametrically tested for maximized value on a project. In contrast, prescriptive design methods are characteristically opaque – they are either pass or fail, true or false - and do not always efficiently mitigate project-specific risks or stakeholder concerns.

The establishment of performance criteria prompts thoughtfulness and consideration from the specifier and often leads to solutions tailored to the specific needs of the project.

3. Integrate form and function

Form and function come together most effectively when aspirational goals manifest themselves as tangible elements of the building. This happens when project teams reduce such building elements to their essential components, making possible elegant responses to the unique set of project constraints. Reducing design elements to their simplest form enables the team to move on to the next step with confidence. When looking back on the project delivery process, such decisions are easier to defend.

Figure 1. CUMGEB is located at the north edge of Columbia University's Washington Heights campus near the George Washington Bridge. (Source: (left image) Diller Scofidio + Renfro / (right image) Matthew Melrose)

4. Find the root: identify where simplicity matters most

Resolving the root cause of a project concern, as distinguished from the myriad of potential challenges that flow from it, is the best way to preserve and enable a project team's design intent and corresponding aspirations when facing risks and challenges. Failure to identify the root cause of any concern can lead to the loss of key design elements.

For example, fear may be at the root of a concern caused by a particular design on the project, and thus clarity, rather than change, may be the best way to address the issue. Endeavoring to identify the root of issues causing concern or complexity, then searching for simplification, is an effective way to execute the project while preserving the project's abstract goals.

5. Realize the aspirations one narrative at a time

In order to move a project forward, it is more important to create a compelling project delivery narrative in each phase than to bring all items to complete resolution.

It is important on projects with high qualitative aspirations to spend sufficient energy building confidence in the process of delivery without the premature demand for full resolution on each item. Comprehensive resolution of the building's design is not realized until construction is complete, as many challenges are resolved across the phases, and what is considered "essential" in one phase can shift throughout the project delivery process.

It can be tempting to drop a design element or idea to create a sense of completion at an early phase, when in fact what serves the project's aspirations best is a compelling narrative of the path forward that can be executed in subsequent work.

6. Leverage state-of-the-art technology, materials, and systems

Leveraging state-of-the-art technology, materials, and systems enables project delivery teams to expand the set of options from which effective solutions can be selected, enabling risks to be surmounted and aspirations realized.

In this context, leveraging refers to taking known and proven technologies and applying them in creative ways to maximize their direct benefits or to indirectly strengthen one of the previous five principles. This sixth principle can mean inventing new technologies, but this is not necessarily essential. Cutting-edge technologies, materials, and systems are tools that can provide access to an elevated level of economy, efficiency, and precision to mitigate quantitative risks, which reliably benefits projects.

An examination of the Columbia University Medical and Graduate Education Building demonstrates how these principles can be manifested in the design and delivery process of an actual project, one which has enabled the realization of the project team's comprehensive aspirations.

The Building: Overview and Goals of CUMGEB

The Columbia University Medical and Graduate Education Building (CUMGEB) is a 100,000 sf, 15 story, state-of-the-art medical educational facility with multifaceted goals of linking students and teachers, interdisciplinary study and interactive learning, function and experience, all while providing an identity and focal point for Columbia University's Washington Heights campus. CUMGEB aspires to be an iconic facility for the university and neighborhood, and also to attract the world's top medical students.

At its core, the building is "an instrument of learning conceived to foster creative exchange and a collaborative spirit among students and faculty as well as a place of respite, relaxation, and social interaction". As stated by the project's design architect, Diller, Scofidio, and Renfro (DS+R), "the rejuvenated campus will represent the highest aspirations of medical education in the world. It will be visually porous and inviting, reconnecting students, faculty, and the city. It will perform its civic responsibility with its urban neighbors. The campus will engage the neighborhood, activate the surrounding streets, and embrace the urban medical center."

These intentions point towards the breadth and depth of the aspirations for the project beyond its technical challenges.

Response to Site: The Study Cascade

The zoning restrictions of the site give rise to a taller building with limited floor plate size, which has an impact on functional adjacencies and distribution of programing. According to the design architect, "the challenge is to transform a traditional college environment with horizontal organization and large footprint into a vertical organization that links floors experientially and functionally, while creating the spatial connections and programmatic relationships essential to supporting the new curriculum for interdisciplinary study and interactive learning."

To achieve these multifaceted goals within the constraints of the site, CUMGEB's public space is arranged vertically into a "Study Cascade" on the building's campus-facing southern façade (see Figure 2). The Study Cascade contains

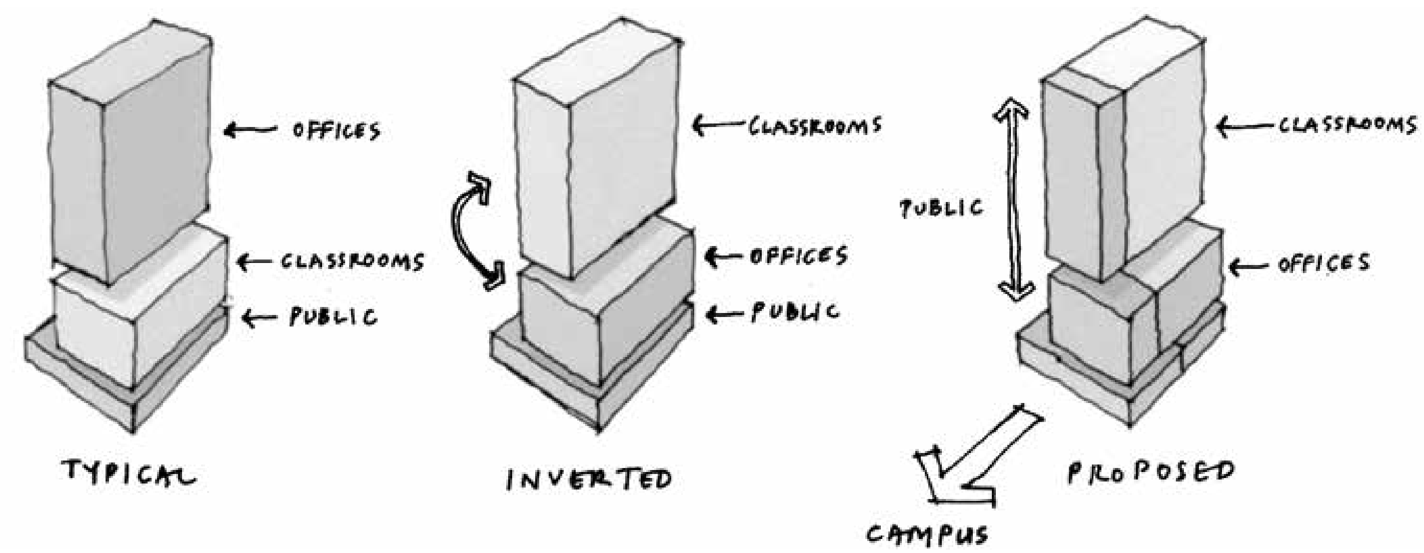

Figure 2. Building massing diagram identifying the vertical arrangement of public space on the campus-facing south façade, defining the "Study Cascade". (Source: Diller Scofidio + Renfro)

Figure 3. "Wood-lined living room" of the Cascade and corresponding structural challenges of varied spatial planning. (Source: (left image) Diller Scofidio + Renfro / (right image) Leslie E. Robertson Associates)

interconnected study and social spaces that encourage collaboration between students. DS+R explains the Study Cascade as "an urban gesture that turns the street up the building to cap the northern limit of the campus, a sculptural feature of the building's south facade that gestures toward the full campus, and an interior space strategy that provides the school with a distributed, wood-lined living room for informal learning and interaction" (see Figure 3).

The northern half of the building is organized for interactive classrooms and administration spaces that are flexible to adapt to the future needs of medical education.

Cascade Components

To achieve the vision for the Study Cascade, which is the most important feature of the building's design, various architectural design strategies and components are employed, each bringing unique execution and construction challenges. A highly transparent façade, consisting of a glass wall that is supported by glass fins without steel mullions, opens the building to the surrounding neighborhood. Various types of spaces - public and intimate, large and small, one-story to three-story, indoor and outdoor, formal and informal - are all stacked into vertical "Academic Neighborhoods". A series of stairs, ramps, and sloped spaces are arranged to facilitate and encourage circulation through and throughout these neighborhoods.

Tangible Challenges

General:

Due to the building's location and to the programming requirements of the project, there are several general design challenges. The building footprint is small – approximately 137 feet x 48 feet at the upper floors. This small footprint, combined with the demanding requirements for vertical transportation set by the academic rhythm of the building, results in a core services area that is a proportionally high percentage of the floor area. The highly transparent design and the relatively large core area restrict the zones for MEP distribution. Additionally, the inclusion of an Anatomy Lab in the building's program further amplified the MEP challenges.

Structural:

The development of a vertical load path through the Study Cascade that respects the varied spatial planning of the stacked neighborhoods is CUMGEB's main structural design challenge (see Figure 3). Given that the cascade is a vertical campus with program elements that do not trend towards alignment, there is an organizational pressure for the locations of supports at each floor to be varied through the height of the building. In a building with such spatial constraints, it is natural for the structure to exert itself on the architecture at some point, and the question is where that should occur.

The articulated façade and diverse programing of the cascade requires that the structural system be easily adaptable to the varying floor-to-floor slab edge positions and support conditions of the façade, lending the form of the building towards cantilevers, where the supports can be kept away from complex edge conditions (see Figure 4). Also, planned spaces, such as the Anatomy Lab and Auditorium, require long spans within the lower portions of the building, further complicating the superstructure.

Logistical:

In addition to various design challenges, CUMGEB faced multiple logistical challenges

Figure 4. South elevation showing cantilevered slabs with varying floor-to-floor slab edge positions (Source: Matthew Melrose)

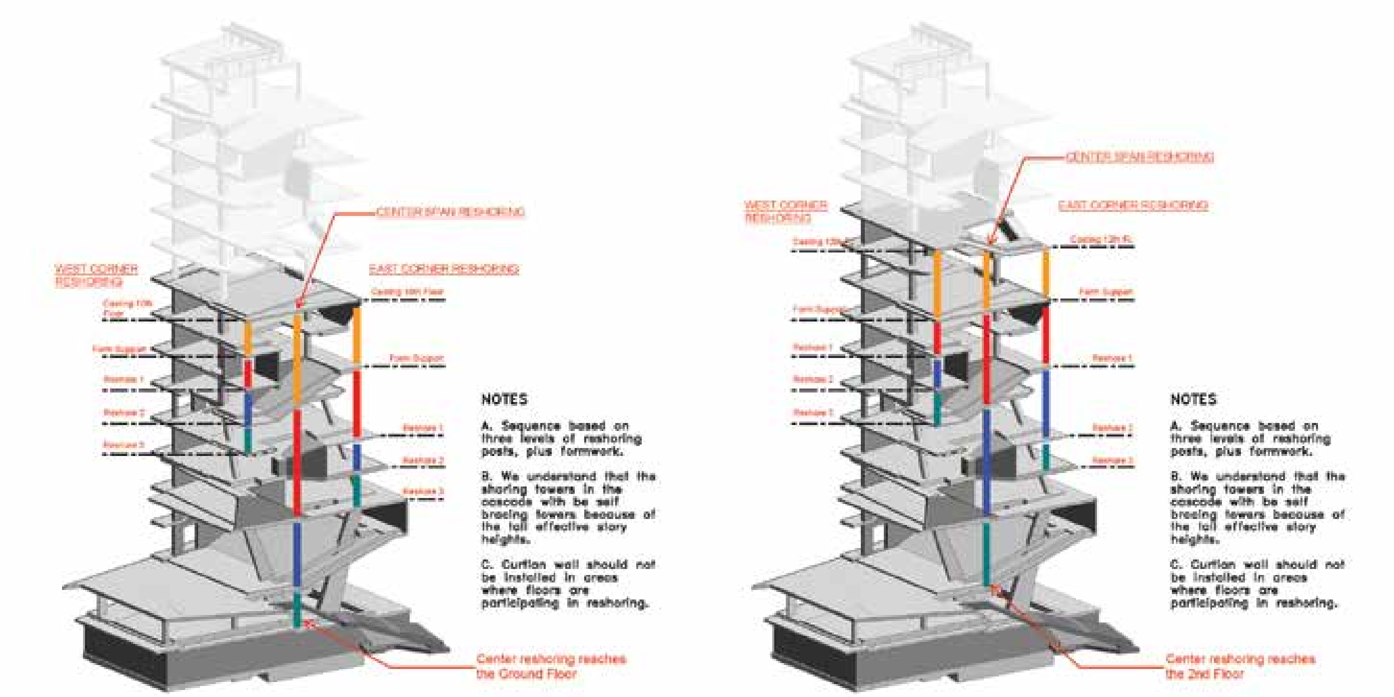

Figure 5. Due to variation in support arrangements of the Cascade, concrete reshoring requirements varied along the south façade of the building (Source: Diller Scofidio + Renfro)

due to its site. These challenges include a small and constrained site, a very windy site, harsh winter conditions affecting construction, and close proximity to functioning buildings, including an active parking garage, university dormitories, and residential buildings. The site contained high bedrock, requiring that any below grade construction would necessitate extensive rock chipping and elevated cost.

Economic Market and Timing:

The project began during the recession following 2008, which affected both the design and construction markets. Though not addressed in detail by this paper, the fiscal related challenges faced by the project delivery team cannot be overstated. Market conditions varied during the life of the project. The design phase began during the recession, when markets were competitive and the industry was hungry for work. By the time the project went to bid, the market had largely rebounded, resulting in fewer interested builders and less competitive pricing. This development required an exceptionally collaborative effort by the owner, architect, and construction manager to keep the vision for the project vision intact and the schedule on track. Sciame Construction and Columbia University worked diligently and successfully on these fronts.

Application of Principles to CUMGEB Delivery

The challenges faced by the CUMGEB project are broad, formidable, and tangible. The project's aspirations are far-reaching and deeply rooted in transforming medical education and social interactions within the city. By fostering a decision making environment grounded in these principles, and environment which mitigates risks without marginalizing broader project aspirations, the project team endeavored to successfully deliver the building.

The CUMGEB project was conceived, developed, and executed by a collaborative team comprised of many members,

Figure 6. Cascade reshoring during construction (Source: Matthew Melrose)

Figure 7. Construction materials: slab void formers placed between bands of bonded post-tensioning (Source: Matthew Melrose)

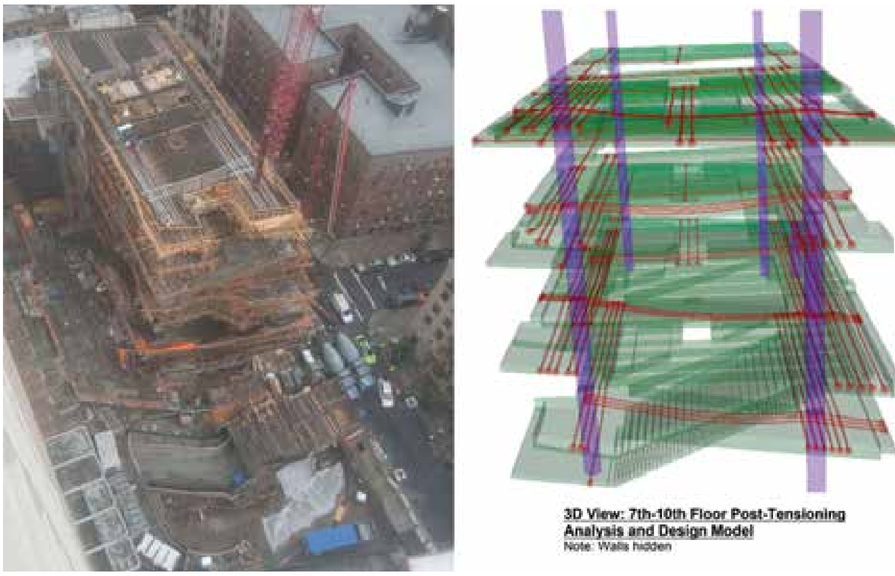

Figure 8. Bonded post-tensioning system as idealized during structural analysis and as constructed (Source: Columbia University Left / Leslie E. Robertson Associates)

including Columbia University, DS+R, Gensler, Scape, Group PMX, Sciame Construction, Leslie E. Robertson Associates (LERA), JB&B, Buro Happold, and others.

The following is an examination of how each principle was applied to the CUMBEG decision making environment and the subsequent results.

1. Engage in an early and active dialogue between stakeholders

The active dialogue between stakeholders was established when the owner engaged the construction manager during the project's design competition, enabling a broad evaluation of systems from the conception of the project. Critical design team members were also engaged from the design competition phase forward. Preconstruction services and contractor input were critical components of the early design phase decisions for the CUMGEB project, including the establishment of the building's major systems such as the structure, façade, etc. Special construction considerations, such as the multi-story reshoring requirements of the concrete superstructure, were early discussions between the construction and design teams (see Figure 5 and 6).

The active dialogue continued throughout the design phases when concrete contractors were engaged for preconstruction services in the Design Development phase and beyond. Contractor's input stressed the importance of reduction in soffit transitions to minimize formwork costs, leading the team to use a void former system to eliminate waffle slab/two-way joist systems in the long-span areas of the project. Use of slab void formers (see Figure 7) was extended throughout the building, reducing the structure's self-weight by 8% and slab reinforcing materials (rebar and post-tensioning) by the same amount.

The project delivery team also engaged the curtain wall contractor in a Design Assist role starting in the middle of the Design Development phase. By engaging the CW contractor this early, the complex façade system was delivered within the project's design parameters and budget, achieving the all-glass wall that is central to the design architect's vision.

The active dialogue was central to creating the effective decision making environment of the project and establishing the trust between the project stakeholders, including the owner, architects, engineers, and contractors.

2. Identify performance based systems and establish criteria

Utilizing an active dialogue between stakeholders, the project delivery team identified that performance based design principles could be applied to the concrete superstructure of the building in order to facilitate effective coordination with the intricate all-glass cascade façade system. In addition, the performance-based design approach to the structure could address concerns that select stakeholders had regarding the suitability of concrete for the building.

Performance-based design principles were established to develop two systems within the superstructure: one for the deflection performance of individual floors or neighborhoods that were post-tensioned, and the other for sequence-related column

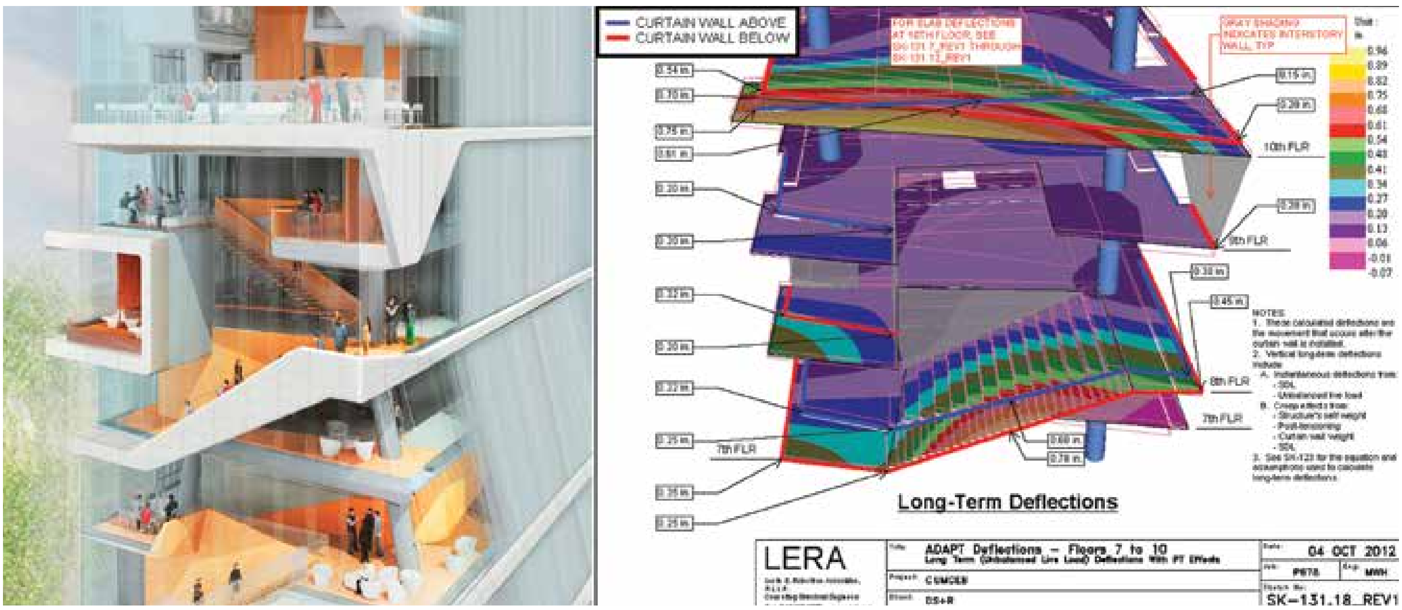

Figure 9. The cantilevered slab performance was coordinated by "neighborhood", here in Floors 7 through 10, with the façade system requirements during a design assist process with the Curtain Wall Contractor (Source: Diller Scofidio + Renfro left /Leslie E. Robertson Associates)

Figure 10. Form and function of the Cascade: the architectural design manifested through the structural interconnection between floors (Source: Diller Scofidio + Renfro left /Fadi Asmar right)

Figure 14. Combination of state-of-the-art materials and technology: void formers, high strength rebar, high strength concrete, and structural steel embedded in columns form the Auditorium structure at the base of the Cascade (Source: Matthew Melrose)

shortening of the cascade structure and its effect on the curtain wall installation approach.

By selecting a post-tensioned concrete structure (see Figure 8), the deflection performance of the building's slabs could be tuned to meet the agreed-upon performance criteria necessary for effective detailing of the cascade's curtain wall. The post-tensioned structure was designed so that the long-term deflections, including creep effects, along support lines of the curtain wall were limited to 1-1/4" or less (see Figure 9). To address the column shortening phenomenon, the team undertook extensive structural analyses of the building and elected to construct the cascade slabs with a super-elevation pre-camber, similar to common practice in tall building construction.

The establishment and evaluation of system performance criteria was an essential tool used to successfully resolve major design and construction challenges for the building.

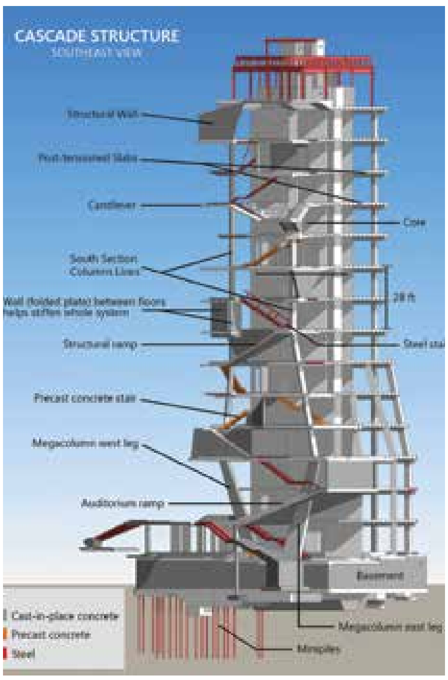

Figure 11. Overview of the structural components of the Cascade (Source: Leslie E. Robertson Associates)

3. Integrate form and function

By tightly integrating the superstructure of the cascade with the architectural form, the project team was able to reduce the cascade to it's essential components, thereby strengthening the architectural aspirations of function and experience, of spatial connection and programmatic relationship (see Figure 10).

This approach grounded the decision making process for the design of all structural elements of the cascade. The cantilevered slabs are interconnected between floors with single-story walls and/or ramps that stiffen the cantilevers. Each architectural wall in the cascade incorporates this structural stiffening effect and reduces the concrete and reinforcing materials of the slabs, which subsequently enforces the functional form of the cascade. See Figure 11 for an overview of the cascade's structural elements.

The floor slabs themselves are tapered to minimize slab thickness at the edge of the building, which is generally limited to 8", and to maximize slab thickness over the columns where the floor slabs are most heavily stressed. Tapering the cascade slabs towards the core addressed the contractor's recommendation to minimize slab soffit steps as a way to reduce cost. North of the cascade, the slab thickness is a constant 14" and satisfies the diaphragm strength requirements of the floor plate while managing slab weight through the use of void formers.

In the execution of the cascade, the principle of the integration of form and function was at the very heart of the decision making process.

4. Identify where simplicity matters most

Simplifications in one place can create complexities elsewhere. Through the active dialogue between stakeholders, the team determined that the benefits of using of a post-tensioned slab system for the superstructure, which could integrate the architectural form of the cascade and provide reliable deflection performance, were more important than the resulting challenges and complexities that come with the use of post-tensioning in the NYC market.

The engineering team accomplished extensive analysis of the deflection performance of the post-tensioned building early, in the SD phase, to provide clarity and develop the project team's confidence in the use of bonded post-tensioned cantilevered slab technology. In doing so it was possible to overcome concerns associated with utilizing a system not widely adopted in the NYC building market and to leverage the system towards accomplishing the architectural aspirations for the project.

Simplifications resulting from the use of post-tensioning included the effective control of deflections and the reduction of concrete and reinforcement materials. Full realization of the benefits of the post-tensioned system required the buy-in of stakeholders as it related to training and subsequent management of the trades accomplishing the work.

Similar efforts were accomplished to evaluate and implement the use of high strength concrete, high strength reinforcing steel, void formers, and structural steel embedded in columns.

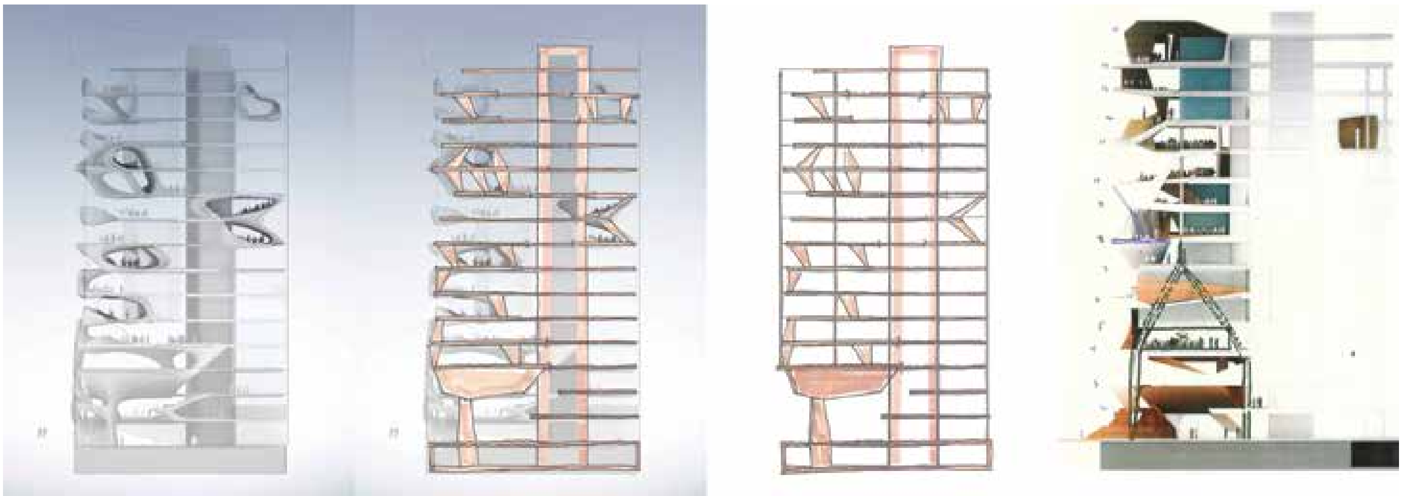

Figure 12. Competition-phase visual narrative that identifies the fundamental framework of the Cascade's structure and sets the stage for systems development in future phases (Source: Leslie E. Robertson Associates)

5. Realize the aspirations one narrative at a time

As the economy rebounded, the CUMGEB project faced a variety of procurement challenges relative to budgetary goals set during a time when the construction market was less bullish. On typical projects facing similar budgetary concerns, building systems critical to the realization of the qualitative, aspirational goals for the project are often undermined.

On CUMGEB, the project team worked at the end of each phase to create a strong delivery narrative around each of the essential components of the building. This enabled project stakeholders to proceed into subsequent phases with an effective understanding of what future work was required to simultaneously accomplish the technical challenges of the project and meet the budget constraints.

Figure 13. Special attention was paid by the Construction team to unique structural details when building the architecturally exposed columns in the Cascade (Source: Matthew Melrose)

In some cases, the phased delivery narrative included increases to the budget. At other times the delivery narrative included the deletion of a system deemed not critical to the aspirational goals for the project. Most often the delivery narrative included specifically identified items for which additional engineering evaluation could demonstrate viability and/or savings, allowing the team to move to the next phase with confidence (see Figure 12).

The CUMGEB project faced numerous budgetary challenges, and the project delivery team, led by the owner, construction manager, and architects, did a remarkable job applying this principle as a technique for delivering the project with its aspirational goals intact.

6. Leverage state-of-the-art technology, materials, and systems

The CUMGEB project delivery team leveraged the use of several cutting-edge technologies, materials, and systems to expand the arsenal of tools available to create a state-of-the-art façade and structure. These systems are principle components in achieving the design intent of the cascade, and their technical execution was essential to successfully delivering the project.

To execute the transparent façade, an all glass system was detailed using tri-laminate 13" deep glass fins and frameless IGU's to create an enclosure that could span up to 28 feet and would maximize views and connection to the surrounding campus and neighborhood. The façade, spanning between the cantilevered cascade slabs, was coordinated to accommodate the immediate and long-term deflections of the concrete structure. The project team specified a unitized curtain wall system along the west, north, and east faces of the building, limiting the use of the highly articulated all-glass system to the cascade, balancing the design intent with economy and efficiency.

The structure, which relies upon the interconnectivity of its cantilevers, was designed using a state-of-the-art analysis program that incorporated multi-floor post-tensioning analysis (see Figure 9). Use of this program allowed the engineers to take maximum advantage of the interconnections between floors in the design of the post-tensioning system, while delivering a reliable set of deflection data for coordination with subsequent trades. Without exercising the capabilities of this program, more approximate methods for determining post-tensioning requirements and deflections would have resulted in a less predictable system, likely with more reinforcement.

In addition, the following materials were used in the CUMGEB structure: high strength concrete (10 ksi vertical elements and 8 ksi slabs), structural steel embedded in concrete columns and floor diaphragms, high strength rebar (grade 97 ksi), and self-consolidating concrete in architecturally exposed elements (see Figure 13).

No new materials or systems were invented for this project. However, proven materials and technologies were combined with performance-based design principles to realize the project's architectural aspirations and create executable systems (see Figure 14).

Securing the Vibrant Future of our Cities

When realizing a project, it may be tempting for a project delivery team to modify an aspiring design in order to ease its technical and delivery challenges. However, doing so

Figure 15. Current progress and neighborhood (Source: Leslie E. Robertson Associates)

can marginalize the completeness of the project aspirations.

Utilizing the six principles described, a project delivery team can successfully deliver a project that achieves their aspirational goals. Such an approach creates a decision making environment that fosters creative problem solving and robust solutions for realizing inspirational projects. All builders – owners, developers, designers, and contractors - that institute this thinking can contribute to securing the vibrant futures of our cities in all economic conditions.

We encourage all builders to engage with these ideas and to be intentional about the decision making environment that is created on their projects.

Construction of CUMGEB is underway (see Figure 15) and, as this paper is being written, the installation of the façade at the Study Cascade is ongoing. While progress towards fulfillment of the wide-ranging aspirations for the project continues, one thing is clear: the constructed building is a near perfect reflection of the original design concept, whole and complete in its realized form.

This success is due in large part to the decision making environment utilized by the project builders, which was rooted in the six principles described above.

Time will tell if CUMGEB achieves the comprehensive aspirational goals established by the project's stakeholders, but an examination of the how the six principles were applied to CUMGEB can be instructive for all builders.