cross sections

Magazine for the Structural Engineers Association of New York
2022 VOLUME 27 NO. 2

SPECIAL ISSUE

2022 EiSE Awards

STRUCTURAL ENGINEERS ASSOCIATION
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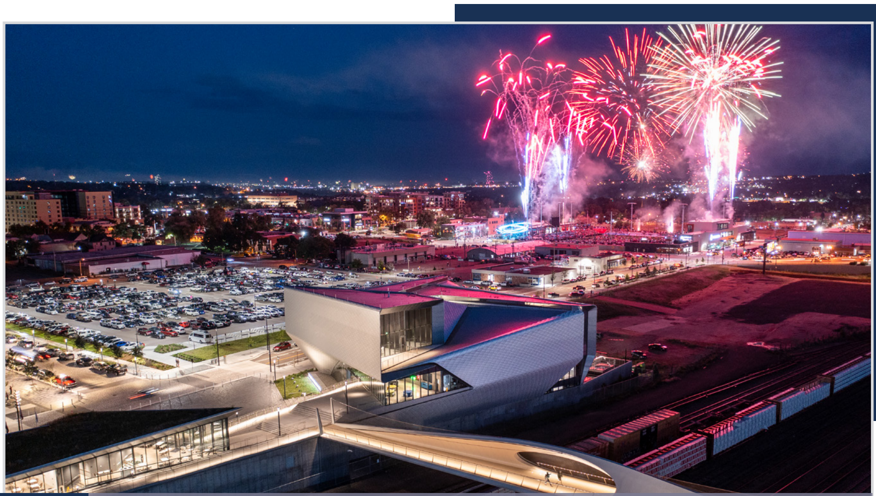

5 EXCELLENCE IN STRUCTURAL ENGINEERING (EISE) AWARDS
WINNERS AND FINALISTS

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PRESIDENT'S MESSAGE

EUGENE KIM, P.E.

Hello SEAoNY Members!!! Can you believe it?! It is the summer of 2022 and with some luck the Annual Boat Cruise is back! With the boat cruise, the Excellence in Structural Engineering Awards (EiSE) presentations are also in person. For anyone that does not know, the Excellence in Structural Engineering (EiSE) awards recognizes the amazing projects our members have worked on. The winning projects demonstrate creativity of complex design, innovative use of materials and techniques, and showcase sustainability.

This year we had over 20 submissions from a dozen different firms. Entries fall into 3 different categories: New Buildings, Forensic Analysis/Renovation/Retrofit & Rehabilitations, and Other Structures. In addition to the 3 major structural categories, we also have our Young Engineer of the Year Award. This award is for an engineer that is younger than 36 years old and has contributed to our industry and community.

I would like to thank this year's excellent panel of judges: SEAoNY Honorary Member Tom Scarangello of Thornton Tomasetti, Michael Alacha of Related Hudson Yards, Evan Akselrad Adjunct Assistant Professor at Pratt Institute, Past SEAoNY President Bradford Kiefer of K&S Engineering, and Kevin Schorn of Schorn and Adjunct Assistant Professor at Columbia University.

I would also like to thank our EiSE platinum sponsor CAST CONNEX and our two EiSE gold sponsors Atlas Tube and Structural Technologies. The continued support of our sponsors is always appreciated and greatly contributes to the programing that SEAoNY offers.

Congratulations to all the winners and finalist of this year's EiSE awards. As you read through the description of the finalists, be sure to consider which of your projects to submit for next year. Good luck to everyone. See you on the boat!

Finally, I will again ask for more members to step up and volunteer some of their time to SEAoNY. Please take a look through our long list of committees (https://www.seaony.org/Committees). All of our committees are always on the lookout for more people to provide their time and input. Any help is appreciated. Structural Engineers at all levels of experience are welcome and encouraged to participate. It is a great way to connect, interact and learn from others in our profession. The purpose of SEAoNY is to advance the art of structural engineering in New York by improving the flow of ideas and building the community of colleagues. And one of the best ways to do that is to be a part of one of our committees.

Sincerely, Eugene Kim, P.E.

EDITOR'S MESSAGE

RIYA MANIAR, E.I.T.

In this issue of Cross Sections, we are celebrating excellence in structural engineering! Structural engineering is changing and improving constantly and we as an industry drive these changes. The articles in this issue and the noteworthy projects in this year's SEAoNY Excellence in Structural Engineering (EiSE) Awards highlights this drive for innovation in the past year. Furthermore, this issue pays tribute to Dan Eschenasy and Tim Lynch for their contributions to the industry throughout the years, as well as celebrates the young members EiSE finalists that will contribute to the future of the industry. Both reflecting on where we have been and where we are going showcases the impact we have as structural engineers at the forefront of innovation on the built environment.

As always, thank you to the publication team, authors, and readers of Cross Sections for your continued efforts into making this publication possible.

Thank you,
Riya Maniar, EIT

DOB STAFF UPDATES

DAN ESCHENASY AND TIM LYNCH RETIRE FROM THE NYC DEPARTMENT OF BUILDINGS

DAN ESCHENASY
PE, SECB, F.SEI

Mayor Eric Adams commemorated April 14, 2022 as Dan Eschenasy Day in honor of Mr. Eschenasy's retirement. The commemoration stated: "Dan Eschenasy PE, SECB, F.SEI, has served as Chief Structural Engineer of both the NYC Department of Buildings (DOB) and the NYC Department of Design and Construction (DDC), and is now retiring after decades of distinguished public service to the People and City of New York.

During his time in service as Chief Structural Engineer at DDC, he led and coordinated the city's engineering efforts at Ground Zero following the terror attacks and major devastation of 9/11. During his time in public service as Chief Structural Engineer at DOB, he founded the agency's Forensic/Investigative Engineering Group, and was a leader of the city's engineering response during multiple natural disasters, including Superstorm Sandy."

Dan is an Honorary Member of SEAoNY and has written for many publications including Cross Sections and Structure Magazine and was a keynote speaker at this year's NCSEA Summit in New York. Dan is still active on the NYC Building Code Committee with DOB and the SEAoNY Code Committee.

TIM LYNCH
PE

After an amazing career with DOB, Tim Lynch has also recently retired from the Department of Buildings after over 15 years. He became "the city's go-to engineer for disasters for extreme engineering challenges".

He has served in multiple roles at DOB including as Chief Inspector of the Forensic Engineering Unit, Assistant Commissioner of Investigative Engineering Services, and Chief Inspector of the Excavation Unit, the latter being a new enforcement unit which he created and founded.

Tim has served on the SEAoNY Board of Directors multiple times and is an active member of the SEAoNY Code Committee and the NYC Building Code Committee through the DOB. He was profiled three times by the New York Times.

THE WORK OF BOTH DAN AND TIM HAS CHANGED OUR PROFESSION AND SAVED LIVES.

SEAONY WOULD LIKE TO THANK THEM FOR THEIR SERVICE.

2022 EiSE AWARDS

RENOVATION / RETROFIT / REHABILITATION

WINNER

PHOTO COURTESY OF SILMAN

The former Mid-Manhattan Library, originally built in 1914-15 as a department store, is the New York Public Library's largest circulating branch.

Until recently, the structure's interior still had constraints related to the space's original functions. Work at the site fell into two main categories: a vertical expansion and renovations within the existing six-story structure. The new vertical addition, which required structural reinforcements, has a conference center and rooftop terrace.

A new "Long Room" with the library stacks and meeting areas features a triple-height atrium. Now renamed the Stavros Niarchos Foundation Library, the building has a LEED Silver certification goal.

PROJECT

NEW YORK PUBLIC LIBRARY

SAVROS NIARCHOS FOUNDATION LIBRARY

DESIGN FIRM

SILMAN

2022 EiSE AWARDS

RENOVATION / RETROFIT / REHABILITATION

FINALIST

PHOTO COURTESY OF DEERFIELD

The Cure repurposes a century-old building to create a home for a state-of-the-art life sciences incubator. Challenges included inheriting a project already in construction and recalibrating the design to meet the new owner's needs. We contended with tight deadlines, unforeseen site conditions, procurement issues and logistical considerations.

The project also required close collaboration between our engineers, the architect and the mechanical engineer to coordinate intricacies including three-tier equipment platforms at the penthouse that optimize useable space in the floors below. The project has brought new jobs to the city and helps establish the city as a leader in the industry.

PROJECT

CURE: INNOVATION CAMPUS

DESIGN FIRM

THORNTON TOMASETTI

2022 EiSE AWARDS

OTHER STRUCTURES

WINNER

PHOTO COURESY JASON O'REAR

Arup is the Engineer of Record for the Park Union Bridge, opened to pedestrians in July 2021, connecting the U.S. Olympic & Paralympic Museum to America the Beautiful Park and Downtown Colorado Springs.

Called the rip curl for its cresting design, the footbridge spans 250ft over active rail lines. The 300 ton steel superstructure is designed to both integrate with the aesthetic vision for the museum and to minimize impact on rail operations during construction.

PROJECT

PARK UNION BRIDGE

DESIGN FIRM

ARUP

OTHER STRUCTURES

FINALIST

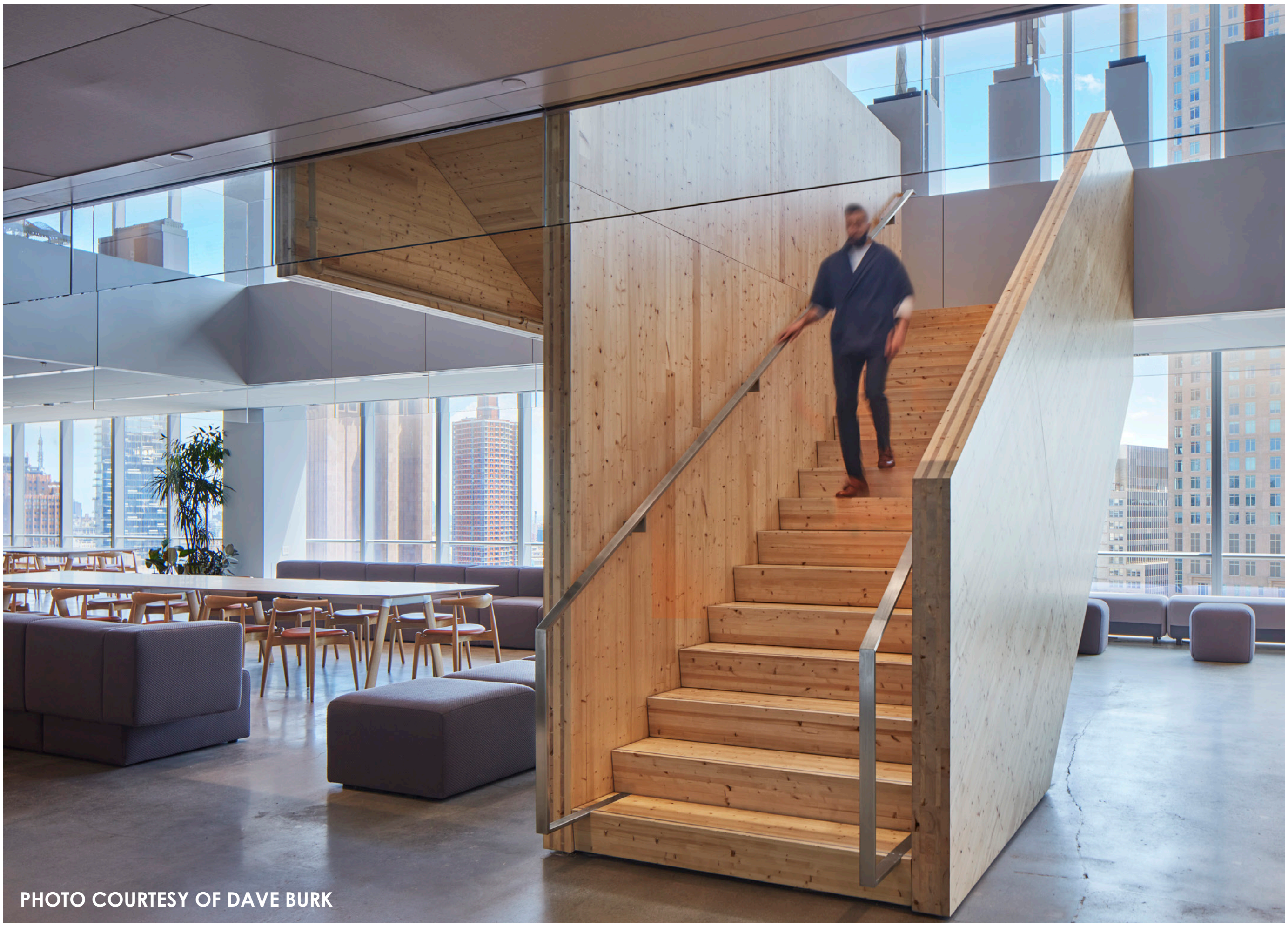


PHOTO COURTESY OF DAVE BURK

In 2021, Skidmore, Owings & Merrill moved its New York studio to 7 World Trade Center, the 52-story office tower the firm completed in 2006. In designing its own space more than a decade later, SOM developed an 80,000-square-foot workplace that fosters collaboration and community, with a focus on four main tenets: openness, mobility, sustainability, and wellness.

The cross-laminated timber (CLT) communicating stair embodies all four tenets. And it does so while solving the complex challenge of introducing a new staircase within an existing building—navigating access limitations and available structural capacity with a solution that's durable, lightweight, and beautiful.

PROJECT

SOM NEW YORK OFFICE CLT STAIR

DESIGN FIRM

SKIDMORE, OWINGS & MERRILL

2022 EiSE AWARDS

OTHER STRUCTURES

FINALIST

PHOTO COURTESY OF ARUP

The Centennial Plaza is a downtown landmark in the city of Canton, Ohio. What was previously an underused grassy square now consists of a two-acre landscape which features an event lawn, integrated performance stage, and two iconic structures.

The first structure – the Rotunda, is a sculpture made up of four 65-foot-tall spires which are fabricated from architecturally exposed stainless steel.

The spires curve and stand in a formation which resembles an American football – inspired by the city of Canton's most prized attraction, the Pro Football Hall of Fame. The second structure is an architecturally exposed steel canopy known as the Pavilion, painted white and clad with vertical fins that provide shading.

PROJECT

CANTON CENTENNIAL PLAZA

DESIGN FIRM

ARUP

2022 EiSE AWARDS

NEW BUILDINGS UNDER 100,000 SQ. FT.

WINNER

PHOTO COURTESY PAUL WARCHOL

PROJECT

FRANKLIN & MARSHALL COLLEGE, WINTER VISUAL ARTS CENTER

DESIGN FIRM

SILMAN

The concave inflections of this new building take cues from the site's old growth trees, all of which this project made sure to preserve. A glass-enclosed central forum provides views of a nearby park and a new reflecting pool that doubles as storm water overflow. The building is LEED Silver certified.

Silman designed the upper-level superstructure using light braced frame and moment frame hybrid elements that are concealed within interior partition walls. The hybrid frames are supported on interior cast-in-place concrete cores and cantilever from recessed perimeter walls, producing a canopy effect at the upper levels reminiscent of the surrounding foliage.

2022 EiSE AWARDS

NEW BUILDINGS UNDER 100,000 SQ. FT.

WINNER

PHOTO COURESY OF LERA

The David Rubenstein Forum at the University of Chicago is a new center for intellectual exchange, scholarly collaboration and special events. The 97,000-sf facility consists of a 2-story podium and a 10-story tower of stacked "neighborhoods" with a zinc-and-glass exterior.

A 285-seat auditorium sits above the podium, and a large multipurpose space on the 2nd Floor, called the University Room, can accommodate groups of up to 600 people.

The top of the tower features a flat-floor multipurpose space that can accommodate over 100 people, and offers stunning views of the campus, the Midway Plaisance, the city skyline and Lake Michigan.

PROJECT

DAVID RUBENSTEIN FORUM AT THE UNIVERSITY OF CHICAGO

DESIGN FIRM

LERA CONSULTING STRUCTURAL ENGINEERS

2021 EiSE AWARDS

NEW BUILDINGS UNDER 100,000 SQ. FT.

FINALIST

PHOTO COURTESY OF DESIMONE

This project included the demolition and replacement of the High C Gates concourse at the DFW International Airport. The project was divided into two major segments: Core and Shell, and InteriorFit Out. Henderson Rogers provided engineering services for the Core and Shell deliverable.

The new 80,000 sf concourse consists of six individual modules constructed off site using conventional steel framing that were then moved to the terminal site using SPMTs (self-propelled modular transporters) and set on concrete columns. Once the modules were set in place, additional steel framing was erected to fill in the gaps between a few of the modules.

PROJECT

DFW HIGH C GATES DEMOLITION & REPLACEMENT

DESIGN FIRM

DESIMONE

2022 EiSE AWARDS

NEW BUILDINGS - OVER 100,000 SQ. FT

WINNER

PROJECT

THE SPIRAL - 66 HUDSON BLVD

DESIGN FIRM

WSP

Construction technology and logistical issues within urban environments, coupled with evolving requirements led by sophisticated clients and tenants, has resulted in greater complexity within today's super-tall commercial office towers. Engineers must utilize their years of experience in order to adjust to new demands and client needs.

This project exemplifies the multiple complexities and the evolving state-of-the-art. As a leader in super-tall building structures, WSP is in the forefront, working with developers, fabricators and contractors in order to help define the new state of the art therby meeting the needs of the industry for today and for tomorrow.

2022 EiSE AWARDS

NEW BUILDINGS - OVER 100,000 SQ. FT.

FINALIST


PHOTO COURTESY OF SEVERUD

PROJECT

100 VANDAM

DESIGN FIRM

SEVERUD ASSOCIATES

Rising up over 320 feet above the corner of Greenwich and Vandam Streets in Manhattan, 100 Vandam is comprised of approximately 150,000 square feet of luxurious and sustainable residential space. The ground level plays host to a stackable parking facility and a fair amount of curb-side retail spaces, whilst the luxury residential units tower above with undulating green balconies and terraces.

The existing brick bearing wall and timber structures at 100 and 98 Vandam have been salvaged, while being fused with the design and character of the new tower.

2022 EiSE AWARDS

NEW BUILDINGS - OVER 100,000 SQ. FT.

FINALIST

PHOTO COURTESY OF GMS

PROJECT

76 TRINITY PLACE - TRINITY COMMONS

DESIGN FIRM

GILSANZ MURRAY STEFICEK, LLP

GMS served as the structural engineer, building envelope consultant, and special inspector for this new 445-foot-tall, 317,000 gsf building with 32 floors, two basements, mechanical and penthouse levels. The upper floors consist of offices while the podium of the building contains the church's program area, Trinity Commons.

The Trinity Place façade includes the bridge entrance 21'-6" above the street to facilitate access from Trinity Church. The base of the building contains specialty spaces, several of which have wide open clear spans, including TV production, meeting rooms, libraries, music practice rooms, loading dock, food service areas, conference centers, classrooms, and offices.

2022 EiSE AWARDS

NEW BUILDINGS - OVER 100,000 SQ. FT.

FINALIST

PHOTO COURTESY SAVANNA REAL ESTATE

PROJECT

141 WILLOUGHBY STREET

DESIGN FIRM

THORNTON TOMASETTI, INC.

141 Willoughby brings 400,000 square-feet of office and retail space to downtown Brooklyn stacked in a neatly massed 24-story, gold-clad tower. Its unique wedge shape is nestled next to five below grade transit lines and the structure is supported by a combination of deep foundations and a 60" mat foundation.

The mat foundation was poured in March 2021, followed by an eccentric concrete core accelerated by climbing formwork and speedy steel erection. If you blinked, you might have missed the topping out in November 2021. The project was a client's dream: on schedule, on budget, and very few change orders.

2022 EiSE AWARDS

NEW BUILDINGS - OVER 100,000 SQ. FT.

FINALIST

PHOTO COURTESY OF GMS

PROJECT

VIRGIN HOTEL

DESIGN FIRM

GILSANZ MURRAY STEFICEK, LLP

GMS provided structural engineering and special inspection services for the new Virgin Hotel in NYC. The building reaches 478 feet above the curb, encompassing 440,000 sf over 38 stories. The tower is constructed of reinforced concrete and the podium is structural steel to provide flexibility to future tenants.

The flat plate slabs cantilever beyond the columns, maximizing the view for each guest room, reducing the interior span deflections, and increasing the efficiency of the slab.

This project occupies the full block between 29th and 30th Streets along Broadway in Manhattan. The project was substantially completed in December 2021.

2022 EiSE AWARDS

NEW BUILDINGS - OVER 100,000 SQ. FT.

FINALIST

PHOTO COURESY BRAD FEINKNOPF

Harvard University's Science and Engineering Complex (SEC) is the cornerstone building of the school's growing Allston Campus and their most significant new building in a generation.

Its forward-looking design is designed to inspire learning and scientific discovery while showcasing sustainability. Constructed above an existing 250,000 square foot basement, the structural design for this world-leading research and teaching facility faced a number of unique challenges. The building's adaptable, innovative environments support the school's commitment to cuttingedge academic collaboration, create vibrant public spaces at a variety of scales, and set a distinctive architectural tone for the Allston campus.

PROJECT

HARVARD UNIVERSITY - SCIENCE AND ENGINEERING COMPLEX

DESIGN FIRM

BURO HAPPOLD

2022 EiSE AWARDS

YOUNG MEMBER AWARD

WINNER

MARK NELSON

Mark leads the Advanced Technology + Research group in Arup's New York office. The group helps deliver a variety of specialist consulting and engineering services. He is active in such areas as risk and resilience, performance based seismic design, dynamics of structures, design of cable stayed bridges and analysis/renovation of heritage structures. He is driven by applying new techniques, methods and materials to demanding and technically complex problems.

Mark has a particular interest in resilience and the performance of the built environment under multiple and changing shocks and stressors such as hurricanes, earthquakes and climate change. These approaches have been deployed in a wide variety of sectors including data centers, financial industry, utilities and other mission critical portfolios.

WINNER

LEAH PEKER

Leah Peker is a professional engineer devoted to sustainable initiatives and expanding diversity, inclusion, and equity within the industry. She is actively involved with her community as the co-chair of SEAoNY's Sustainable Design Committee.

Leah has taught classes at Pratt Institute and has mentored students through the ACE Mentor Program. She is driven by her dreams of a brighter future, and the power structural engineers hold in the fight for climate action.

Leah seeks out opportunities to support women and people with uteruses and believes that it is imperative that the engineering community take a strong stance to protect abortion rights.

2022 EiSE AWARDS

YOUNG MEMBER AWARD

FINALIST

ALEX JORDAN

Alex Jordan is an Associate at Skidmore, Owings & Merrill (SOM). He has been involved in the structural design of award-winning projects both in New York City and across the world. His portfolio includes high-rise buildings, adaptive reuse projects, long-span airport structures, and designs with complex geometries. In his recent work for Penn Station's East End Gateway, a new entrance into the Western Hemisphere's busiest transit hub, Alex led the parametric research for a two-way curved glass canopy supported by an anticlastic cable net that rises 40 feet. Two blocks to the west, he contributed to the structural engineering of four buildings at Manhattan West, a seven million-square-foot development built above active railroad tracks leading to the station.

Alex completed a dual Bachelors degree in Civil Engineering and Architecture from the Massachusetts Institute of Technology, and a Masters of Science in Engineering from Princeton University. He is a member of several American Society of Civil Engineers Structural Engineering Institute (ASCE-SEI) committees, including the Tall Buildings Committee and the Aesthetics & Design Committee.

Over the last few years, Alex has contributed to the "ASCE Manual of Practice — Design and Performance of Tall Buildings for Wind," and continues to help to promote the manual at various engineering conferences and seminars around the country.

FINALIST

KATHERINE RIVERA

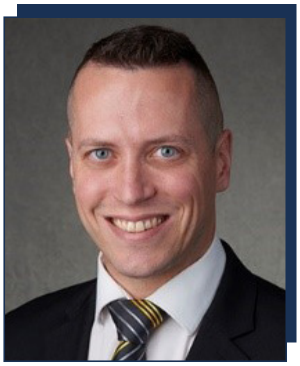
Katherine works as a structural engineer at EDG Architecture & Engineering, specializing in research and development using a parametric approach. She is passionate about her work and enjoys engaging with students to share her love of structural engineering.

Katherine received her Bachelor's and Master's degrees from Columbia University with concentrations in structural engineering and forensics. She has been active with SEAoNY's Student Outreach Committee since 2015 and has served as one of its co-chairs since 2020.

She is also active with NCSEA as a member of the External Communications Committee and as one of the co-chairs of the Students and Educators Committee. Her enthusiasm for life-long learning extends to her dog, Rio, who is currently mastering the leg weave.

A GENOME FOR STRUCTURAL OPTIMIZATION

PARAMETRIC ALGORITHMIC DESIGN OF STRUCTURES



BY STEPHEN REICHWEIN
PE, SE(NV), SECB
SENIOR ASSOCIATE,
SEVERUD ASSOCIATES

BY PHILLIP BELLIS
PE
INDEPENDENT
CONSULTANT

Access to relevant data is essential for quality, fact-based decision making. While engineers have always approached their work with this concept in mind, the modern project workflow has brought about a specific, significant change to the way projects are delivered. Client expectations have grown beyond the concept of a "final" deliverable. It has become common for clients to require a continuous influx of data upon which they base key business decisions; likewise, engineers are now purveyors of data as much as they are consumers of it. In the field of structural engineering, the potential data includes, but is not limited to:

- Structural steel tonnage associated with various framing configurations
- Economies of scale projections for repetitive connection types
- The relationship between steel tonnage and occupancy comfort for various serviceability considerations

The relevant data varies for each project; however, thanks to technological advancements within the last decade, engineers now have a powerful design tool to meet clients' ever-growing demand for data. Parametric Algorithmic Design (PAD) is a process through which structural engineers can deliver results most useful to clients in an efficient manner. Depending on the complexity of the structure, engineers can automate millions of simulations, process data, and have presentation-ready graphics in a matter of hours. This article will explore application of PAD to the design of three structures:

1. Performance/Cost Optimization – Long span truss
2. Performance Optimization - High-rise braced frame core
3. Comprehensive Optimization – Long span grid shell

The topics and examples presented in this article vary from simple to complex, thus offering unique learning opportunities for all readers.

WHAT IS PARAMETRIC ALGORITHMIC DESIGN?

The concept of PAD approaches design as a mathematical function:

- The algorithm is the function itself, comprised of constants, variables and constraints
- The parametric aspect of PAD is the set of variables being explored and the constraints that these variables must satisfy

Rather than test for validity after output has been produced, variables are often associated with a domain to ensure that constraints are satisfied . For example, in the design of a simple truss, the span, supports, and loads are considered constants. The depth of the truss, however, would be considered a variable, hypothetically constrained by the architecture to a depth between 5 and 10 feet. By constraining the variable to values between 5 and 10 feet, the result will conform to architectural requirements.

Once the algorithm is assembled, verified, and the program run to completion, the engineer will have produced design output. In structural engineering, the data output could be in the form of a geometric model, analysis model, member forces, member sizes, or any other format desired by the user.

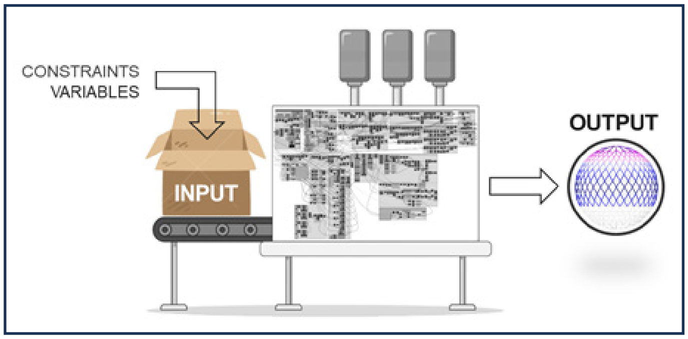


Figure 1: The Parametric Machine, a Simple Function

HOW CAN PARAMETRIC DESIGN BE USED TO OPTIMIZE STRUCTURES?

The process thus far is manual: the engineer develops an algorithm for obtaining certain desired output data. Should the PAD process continue, the engineer would then perform the iterative process of modifying input to obtain results for different permutations of the defined variables . This could be a lengthy process depending on the complexity of the algorithm. Regardless of complexity, it is certainly not the most efficient manner in which to proceed. Enter the use of an evolutionary solver to quickly iterate through the possible solutions.

An evolutionary solver repeatedly runs a design algorithm until it obtains the closest possible result to the user's set target. During each of these runs, the solver identifies the specific variable permutations that produce the most favorable results. The favorable permutations are stored and then incorporated within the next generation of the iterative process to improve upon the solution. This is similar to the evolution of mankind; our genetic code evolves with each generation, the stronger genes prevailing at the highest rate. In PAD, the genetic evolution occurs within the variables of the model. The outcome is the permutation of variables that results in an output closest to the user's set target; in the case of the aforementioned truss, the optimal depth .

As the goals of individual engineers can vary widely, a fitness function is commonly applied when using an evolutionary solver. A fitness function takes the user's goal and converts it to a value to be either maximized or minimized by the solver. The value can be a singular output such as tonnage or self-weight, or it can be the result of a multi-variable function, such as cost. Though it requires research and collaboration with shareholders, cost is often the most impactful fitness function to use when comparing design alternatives within structural engineering. For example, the tonnage of a steel structure is only one component of the total cost. An engineer must also consider fabrication, labor, erection, procurement and other factors. Assume a steel structure has the following costs:

1. Raw Material = $2000 / ton = X
2. Cost per Piece = $2000 / piece = Y
3. Cost per Connection = $1000 / connection = Z

The fitness function for cost becomes:

$FF = 2000 * X + 2000 * Y + 1000 * Z$

Where X, Y, and Z are outputs of the algorithm.

Evolutionary solvers are not a new concept. The most common example is the solver add-in for Microsoft Excel . This add-in allows the user to set the solver to change the value of certain cells within specified constraints. Similarly, Revit/Dynamo has an evolutionary solver called "Optimo," while Rhino/Grasshopper has one called "Galapagos." These are not the only evolutionary solvers available for each of the programs, although they are the most common.

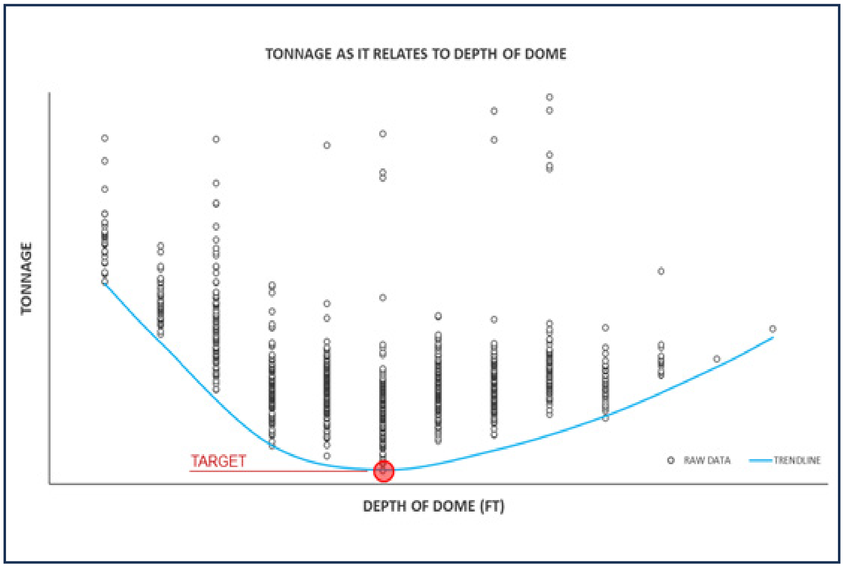


Figure 2: A Goal of Structural Efficiency/Optimization of Weight/Tonnage

AN EXAMPLE OF WORKFLOW FOR STRUCTURAL OPTIMIZATION

There are multiple workflows for structural optimization that incorporate PAD. Through trial and error, engineers find the system that works best for them on any given project. The workflow outlined below is one of many used by the authors and has been successfully implemented on a variety of projects .

To begin, the geometry of the model is built using Rhino and Grasshopper. The algorithm is scripted in Grasshopper and viewed in the Rhino display window. Once the algorithm for the geometry is finished, the structural analysis component is added. There are multiple plug-ins that allow the user to utilize a preferred structural analysis program. The authors prefer to use Karamba3D at this point in the workflow because all analysis takes place within the Grasshopper interface . This greatly increases the speed at which the user can perform iterations of multiple design options. All results are viewable within the same Grasshopper/Rhino window, but they can also be exported in a table format depending on user preference. In this workflow, the results are kept within Grasshopper so that they can be used to run the evolutionary solver, Galapagos, within the same program.

It is up to the user to develop the fitness function that will ensure the desired output from Galapagos The fitness function is entered into the solver, variables assigned, and the optimization run started. The optimization will converge upon a result based on the options selected by the user prior to the onset of the run. All solutions are temporarily saved within the Galapagos window for the user to review prior to making a final selection. Once the solution is selected, the geometry (complete with structural member sizes) may be converted to three-dimensional modeling elements. The authors typically use Geometry Gym for this task. Geometry Gym streamlines the export of models to Revit and other structural analysis programs, such as SAP, ETABS, and RAM. The structural analysis model is then verified, followed by completion of model detailing in Revit.

The example at right is only one of many ways to peel the orange. For example, one may elect to work directly in Revit, either using Dynamo (same as Grasshopper is to Rhino) or RhinoInsideRevit, where users are able to directly manipulate a Revit model using the Rhino and Grasshopper interfaces.

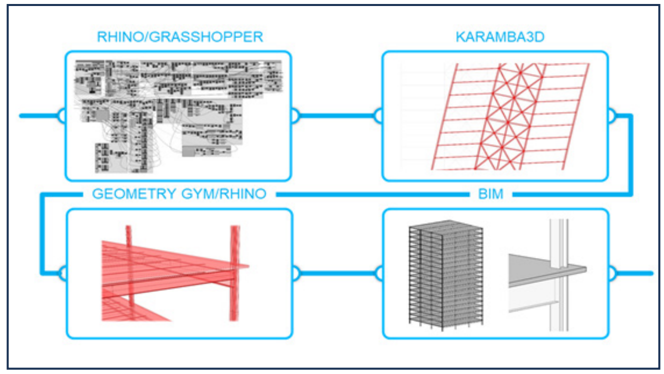


Figure 3: Example of a Common Parametric Workflow

PARAMETRIC OPTIMIZATION OF A LONG SPAN TRUSS

Constraints:

- Span: 125' - 0"
- Depth: Min - 5'. Max - 25'
- Support Condition: Pin-roller
- Load: DL, LL (Evenly distributed along the top and bottom chords)
- Max Deflection: L/240 (TL)
- Structural Shapes: W8, W10, W12, W14 Families

Variables:

- Evenly spaced panels (quantity)
- Truss depth (ft)

Targets:

- Performance Optimization (Minimize Tonnage)
- Cost Optimization

The workflow resembles the general workflow previously discussed: the algorithm and model are developed in Rhino and Grasshopper. Structural analysis is then performed using Karamba3D. Next, the evolutionary solver Galapagos is introduced to the algorithm and the optimization process started. Finally, Galapagos converges on the targets and the optimized result is chosen.

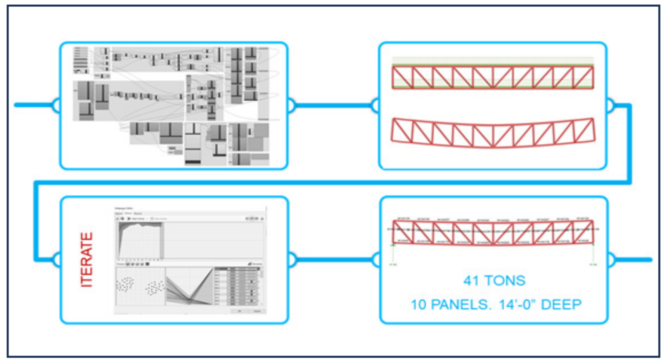


Figure 4: Workflow for the Parametric Optimized Steel Truss

In this case, the optimized result is a 10-panel truss that is 14' deep and weighs 41 Tons. However, this result does not necessarily converge with the Cost Optimization target. The following fitness function will be used to minimize cost:

- Cost = $2,000 / ton raw material + $2,000 / fabricated piece + $1,000 / connection

The evolutionary solver is now run to target the truss with the least cost. As expected, the result does not match the truss from the optimization run for least tonnage. The truss optimized for cost is 6 panels, 16' deep, weighs 46 Tons, and costs $156,000.00. The truss optimized for tonnage costs $186,000.00. This is a savings of $30,000.00 per truss. In order to ascertain the accuracy of the cost function, it is imperative for the steel fabricator and erector to be involved with the optimization process as early as possible. Although an added effort, the client will greatly benefit and likely appreciate the resulting cost savings.

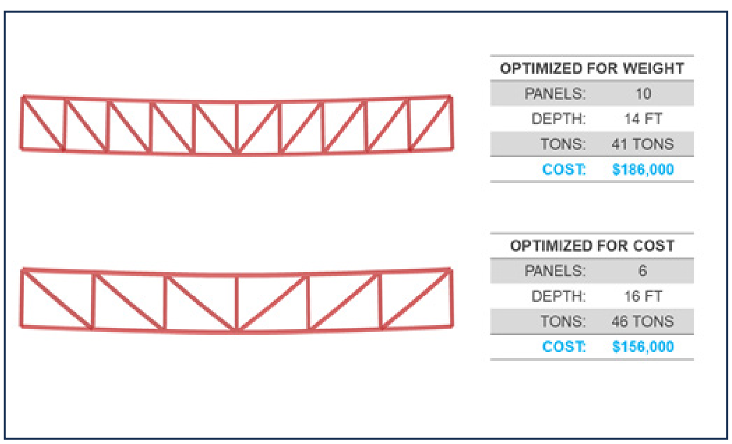


Figure 5: The Parametric Truss, Optimized for Cost

PARAMETRIC OPTIMIZATION OF A HIGH-RISE BRACED FRAME CORE

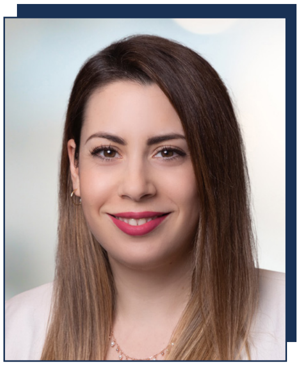
The newest generation of high-rise structures features an aggressive combination of complicated geometry and height. This is made possible by recent advancements in materials, construction methods, and analytical procedures.

Parametric optimization, when combined with these other advancements, can help engineers identify crucial information for design alternatives at the early stage of a project. The most effective solutions can thus be implemented without causing delays or other unforeseen complications as they would with traditional design methods. Examples of structural solutions include: structural form, bracing and outrigger configurations, and custom structural shapes.

In this simplified example, the subject high-rise structure is a 700'-0" tall office building with 35 stories. Each major-axis direction has 3 - 50'-0" bays, the center bay being a 50'-0" x 50'-0" braced elevator core. The building is a 150'-0" x 150'-0" square in plan. The selected parametric workflow is the same as in the previous steel truss example; however, for simplicity, the only optimization of concern is structural tonnage.

STRUCTURAL FIRE DESIGN

WHY, WHEN AND HOW TO LEVERAGE PERFORMANCE-BASED STRUCTURAL FIRE DESIGN



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INTRODUCTION

Performance-Based Structural Fire Design (PBSFD) provides an alternative to the prescriptive fire protection measures of building codes, with benefits that can include improved fire safety, better economy, added design flexibility, and better aesthetics. This paper guides engineers, architects, and owners through several project types most likely to benefit from the application of PBSFD.

To understand the advantages of PBSFD, a comparison to traditional design methods is needed, namely prescriptive fire protection of structures. Prescriptive fire protection is based on fire resistance ratings of individual building components within the structure. The prescriptive method does not evaluate the behavior of these building components as part of a structural system; it neglects consideration of structural connections, thermal stresses, behavior during cooling, and fire effects specific to the physics and geometry of the building and its contents. As a result, prescriptive design leaves room for inefficiencies in design as well as safety gaps, sometimes at the same time. Because structural performance in fire is not calculated when prescriptive fire protection methods are employed, the designer cannot detect and remedy potential deficiencies of structural behavior in fire, nor incorporate elements into the design to improve building resilience.

By contrast, PBSFD is a rational design process that considers the response of the entire structural system and fire protection to realistic fires, with the goal of achieving a specified acceptable performance in fire. Because structural and fire protection design decisions are made to achieve specific beneficial performance of the building, the design is optimal for a given performance goal. Furthermore, explicit design for acceptable structural performance means a more reliable resilient building with better safety than traditional prescriptive design methods for the same level of resources. In summary, PBSFD can improve fire safety compared to traditional design methods for the same level of resources ; or improve economy, aesthetics and building functionality for the same level of fire safety ; in fact, PBSFD frequently provides both sets of improvements to design simultaneously.

STRUCTURE TYPES LIKELY TO GAIN COST SAVINGS FROM PBSFD

A. Structures with large open spaces

In structures with large open spaces, the realistic fire effect on many of the structural elements is likely much less than the standard fire curve prescribed in the standard furnace test of ASTM E119. In a large open space, hot gases from a potential fire have room to disperse. Therefore, the structure is more likely to experience a local fire (a fire in a room) as opposed to the more punishing compartment fire (the room on fire). In addition, with high ceilings the upper elements will be far from the flames, further reducing the fire impact.

Finally, many of these spaces such as airports, stadiums, lobbies, convention centers, iconic structures, gymnasiums, and conference rooms have much less combustible content compared to typical office or residential buildings. This means that these structures can have much less fireproofing without compromising fire safety.

B. Structures with exposed steel members

Clients often use exposed steel for aesthetics or to avoid the presence of cementitious particles in the air for health or manufacturing reasons. However, intumescent coating is expensive and has its own aesthetic challenges. In addition, thicker intumescent coating could mean application in several layers over an extended duration, substantially increasing cost and schedule impacts. As such, where elimination or reduction of intumescent coating on some structural elements is justified by analysis, the cost savings can be substantial.

C. Structures with hollow steel columns

Buildings Buildings with hollow steel columns present a unique opportunity to benefit from PBSFD. The use of concrete filling and sometimes additional reinforcement or embedments can be employed to enhance the structure's behavior in fire while avoiding external fireproofing. Concrete filling improves fire performance in two ways: by providing additional strength when the steel section temporarily loses some of its capacity at elevated temperatures, and by acting as a heat sink to reduce the steel temperatures.

While concrete filling of hollow steel columns is an established prescriptive method of providing fire resistance (See AISC's Design Guide 19 **[1]**), the limitations on its use are numerous. For example, prescriptive design limits use of concrete fill to straight columns with maximum cross sections of 16 inches for round shapes and 12" for rectangles, maximum column effective lengths of 13 feet, and maximum fire ratings of 2 hours. As real project demands often fall beyond these limited applications, PBSFD can be employed to prove through analysis that concrete-filled hollow steel columns of sizes and characteristics outside of these parameters can safely resist their loads during a fire.

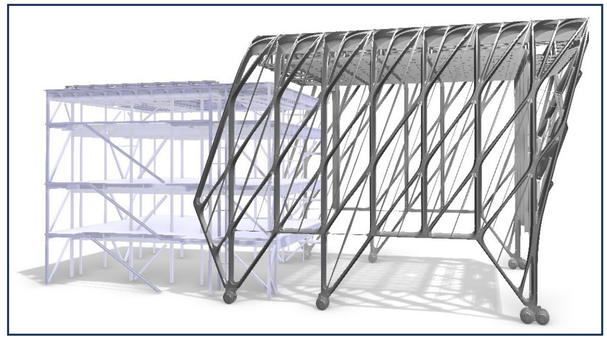

Figure 1: The Shed, New York, NY Photo Courtesy Thornton Tomasetti

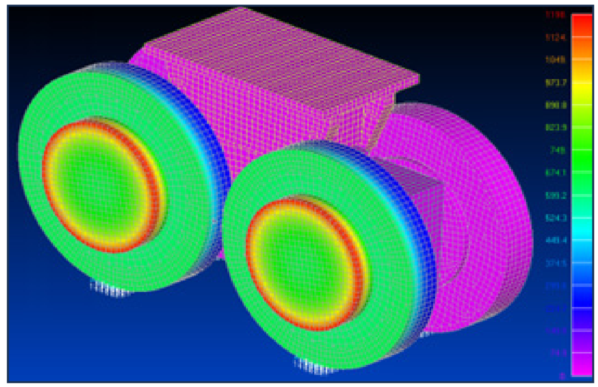

Figure 2: Finite element analysis of the bogies at the Shed, New York, NY
Photo Courtesy Thornton Tomasetti

D. Renovation of existing buildings

Renovation or adaptive reuse of existing buildings presents an excellent opportunity for applying PBSFD. Compliance with new code requirements may have significant implications for the geometry, materials, functionality, and cost of the renovation. However, the building geometry and construction are fixed parameters, and making modifications to them can be very costly and disruptive compared to implementing similar measures in a new design. PBSFD allows for evaluating alternative measures to satisfy the safety goals of the code with less intrusive and costly measures than those possible with prescriptive design methods.

OPPORTUNITIES FOR IMPROVED FIRE SAFETY

Because prescriptive design does not quantify building performance in fire, it can leave safety gaps compared to the presumed performance. For example, full-scale experiments at the National Institute of Standards and Technology (NIST) have shown shortcomings in the performance of a prescriptively designed 2-hour fire-rated two-story structure with steel framing and composite steel deck. The structure was tested for the standard fire, but failed to contain the fire at approximately 70 minutes when large slab cracks allowed flames and smoke to penetrate through the slab into the upper level **[2]**. Similar results have been shown in other experiments and studies, including a comparison of prescriptive and performance-based design for four exemplar buildings published by ASCE **[3]**.

By contrast, PBSFD includes analysis of the detrimental effects of fire on material properties and structural response. Consideration of the quantified fire performance in design allows for mitigating risk and ultimately achieving a more resilient design. This is particularly relevant for structures with higher needs for resilience such as important government facilities, major industrial facilities, corporate headquarters, hospitals, schools, and other essential facilities. Some of the building types that can benefit from the PBSFD process are described below.

A. Buildings that cannot be evacuated quickly

For buildings such as hospitals and institutional buildings that cannot be evacuated quickly, designing the

Figure 3: Pittsburgh International Airport, Terminal Modernization Program, Pittsburgh, PA
Courtesy of Gensler + HDR in association with Luis Vidal + architects

structure to survive full burnout of the building contents in the affected area can provide flexibility for building occupants to shelter within the building if needed. This will also provide fire service with more flexibility on how they approach attacking the fire and aiding the occupants. In addition, agent-based evacuation modeling can be used to identify potential vulnerabilities and devise improved evacuation and transport strategies. Collectively, these measures improve safety by creating safe options that do not rely on rapid evacuation of building occupants.

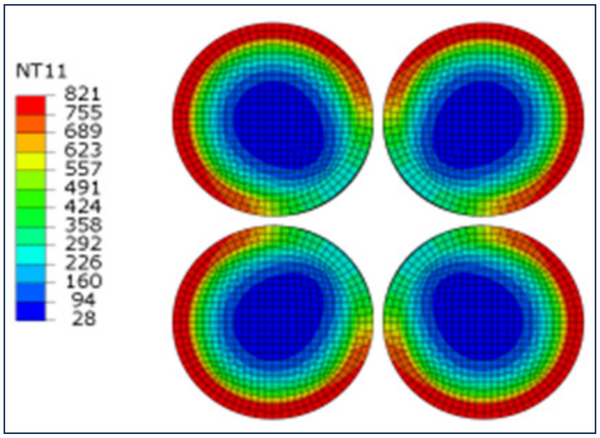

Figure 4: Pittsburgh International Airport, Terminal Modernization Program, Pittsburgh, PA. Temperature contours (°C). Heat transfer finite element analysis of concrete-filled steel HSS column under a realistic fire scenario. The inside space between columns is not exposed to fire. Photo Courtesy Thornton Tomasetti

B. Buildings with different fire loads

If the building contents may result in fires that are different from a typical building fire, PBSFD allows for quantifying and explicitly designing for the potential impact. For example, the building may contain a larger than usual quantity of combustible content. Similarly, new technologies pose the challenge that we do not have significant past experience and data to estimate their impact just based on statistics of past performance. A good example would be a large fleet of electric vehicles or high density of battery energy storage inside buildings.

PBSFD can also be used to combine data related to behavior of heavy timber in fire, results of past experiments, and results of analysis to design safe tall heavy timber buildings. The holistic safety evaluation of the buildings would include structural performance as well as other fire protection systems and egress strategies.

C. Prefabrication and modular construction

Prefabrication and modular construction require construction of various parts or significant portions of buildings offsite and assembling them at the construction site. This process often involves special arrangements and connection mechanisms that are different from standard buildings. PBSFD allows for explicitly evaluating the building performance to account for these differences in construction. The benefits could include improved performance in fire, as well as additional flexibility in considering effective measures to achieve the safety goals of building codes.

CASE STUDIES

The Shed: The Shed is a unique building in New York with a movable shell that slides on wheels towards an adjoining plaza and creates an iconic space for large-scale events. The structure is supported on six sets of steel wheels (or so-called "bogies"). Any fire protection applied to the wheels would be damaged when the structure moves. The design team demonstrated analytically that even with large fire loads, the bogies were sufficiently massive to absorb the fire-induced heat and continue to safely support the building loads without fireproofing. Therefore, PBSFD yielded a solution to a problem that had no prescriptive solution. The large open space also means that even a large local fire will have a limited impact on the exposed steel perimeter columns of the building above a certain height. We worked in partnership with Code Consultants Inc. t o demonstrate that intumescent coating could be eliminated from these elements without impacting safety.

Kravis Center: The Raymond F. Kravis Center for the Performing Arts in West Palm Beach underwent an expansion of the main lobby that included new steel columns and steel beams to support the roof. Because of the large space and high ceiling (approximately 40 ft), it was determined that fireproofing on the upper portions of the columns was not contributing to building safety in fire and was therefore eliminated.

Pittsburgh International Airport: The new terminal, which is currently under construction, has architecturally exposed hollow steel columns. The column stems branch out as they reach toward the roof at the departure level, forming "tree columns." Instead of applying intumescent coating, the columns were filled with concrete and analyzed under conservative realistic fire scenarios. Based on variations of structural demands and temperatures along columns, reinforcement was added up to a certain height at departures level. Because the columns are curved, they carry large bending forces as well. For some branches, an additional embedded built-up steel section was added inside the column at the bent to increase the column capacity. The embedded steel remains cool throughout fire and maintains its full capacity. PBSFD showed that all columns have adequate capacity to carry design forces under design fire scenarios. The result is a safe design whose resistance to fire is intrinsic to the structure and not subject to deterioration over time. In addition, the exposed steel is aesthetically preferred to the intumescent coating texture. Finally, the concrete fill solution reduced the cost for the project by replacing the significantly higher cost of intumescent coating.

Exemplar Highrise Building Design: Prescriptive and performance-based designs of a mixed-use 50-story high rise exemplar building , located in the midwestern United States were compared. The 20 upper floors are residential floors of reinforced concrete construction and the 30 lower floors are office floors with structural steel framing and deck. Interconnected steel

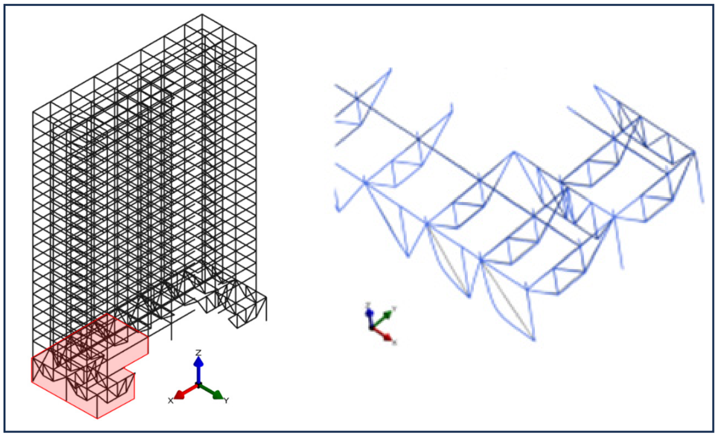

Figure 5: Performance-Based Structural Fire Engineering, Exemplar Designs of Four Regionally Diverse Buildings using ASCE 7-16, Appendix E (ASCE 2020). Finite element model of the upper residential floors and transfer trusses in SAFIR (left), and deformed shape of trusses under a fire scenario (right). Credits: Thornton Tomasetti

transfer trusses at the 30th floor transfer loads from a denser column spacing in the floors above to a wider spacing in the floors below. The analysis showed that a prescriptive code-compliant design did not provide structural integrity for the duration presumed based on the fire-resistance ratings. By contrast, PBSFD allowed for modifications to fireproofing and the structural design to improve safety, economy, and embodied carbon. The improved design could survive burnout of building contents and included changes to the structural connections and a more effective application of fireproofing based on analysis results.

For example, the fireproofing thickness was increased for connections and reduced for beams and columns. The design also focused on the steel transfer trusses whose responses to fire had potential global consequences affecting the upper supported floors. The design team explored several design options with varying fireproofing amounts placed on the trusses. All options satisfied the structural safety criteria but produced different deflection impacts on the upper floors. In an actual project, the design team would select one of these designs based on the building owner's preferences regarding upfront costs versus potential financial impact in case of a fire.

CONCLUSIONS

Performance-Based Structural Fire Design is a rational design process that accounts for unique features and goals of individual projects and explicitly designs for acceptable performance in fire. Because design decisions are made based on their impact on building performance, the result is an optimum reliable design that achieves the expected performance effectively and efficiently. Many types of projects can benefit from PBSFD benefits that include improved safety, cost savings, desired aesthetics, design flexibility, and reliability. This article provides information and examples on when these benefits are likely and tangible.

While PBSFD may be employed at any stage of a project, starting early assures that the project will gain the maximum benefit of performance-based design. A project started with PBSFD will have maximum flexibility in design options as well as adequate time for communication with the design team and authorities having jurisdiction.

Figure 6: The Shed, New York, NY Photo Courtesy Thornton Tomasetti

Figure 7: The Raymond F. Kravis Center for the Performing Arts, Expansion, West Palm Beach, FL
Courtesy of Leo A Daly

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[1] American Institute of Steel Construction, 2003. Design Guide 19: Fire Resistance of Structural Steel Framing.

[2] Choe, L., Ramesh, S., Dai, X., Hoehler, M. and Bundy, M., 2021. Experimental study on fire resistance of a full-scale composite floor assembly in a two-story steel framed building. Journal of Structural Fire Engineering.

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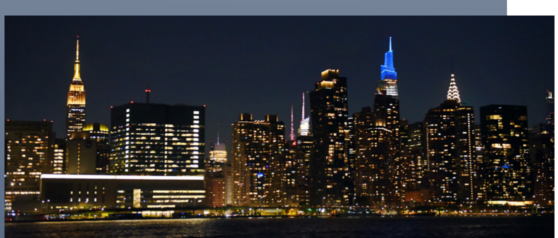

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