The acclaimed architecture, art and advisory firm Svigals + Partners dsigned the innovative Engineering and Science University Magnet School (ESUMS) in Connecticut, a STEM education facility, for the owner the city of New Haven, the host city of West Haven, and the University of New Haven, a partner in the project. (photo by Robert Benson, courtesy Svigals+Partners)

DATA-DRIVEN BUILDING DESIGN & SUCCESSFUL PROJECT OUTCOMES

Using cost estimating with data a key to success / strategies for capturing, analyzing and applying building data

By C.C. Sullivan, Contributing Editor

Data-driven science, control systems and even journalism are in vogue today, reflecting the increasing reliance on real facts and figures – rather than experience or subjective opinions – to drive successful pursuits. In the architecture, engineering and construction (AEC) realm, the same trend is helping make project teams and buildings more successful. The ultimate goal is to enhance value through a process that predicts accurately the cost of a building — even if its architects may not see the construction begin until two or more years after the start of schematic design.

LEARNING OBJECTIVES

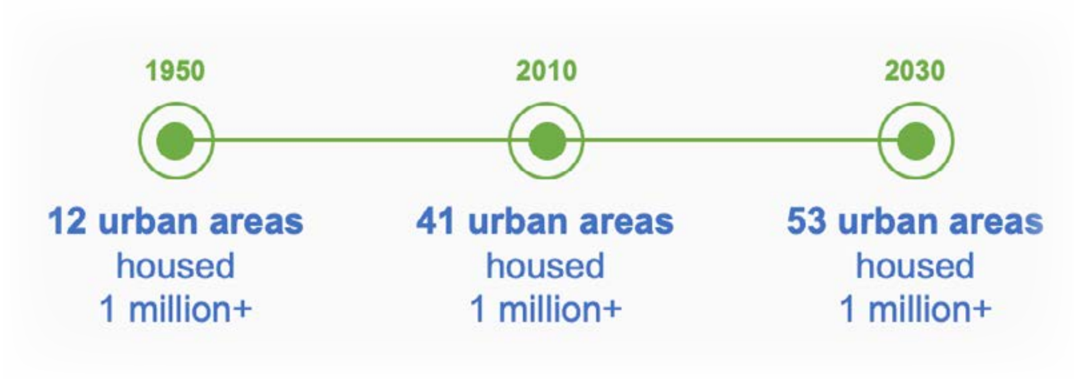
After reading this article, you should be able to:

- **DISCUSS the benefits of using accurate construction cost data for architects and other construction professionals in project delivery and business success.**
- **DESCRIBE how market volatility impacts construction material costs historically, and describe how future volatility may arise.**
- **LIST and contrast at least [six] ways that value engineering may be improved to better align designs with budgets.**
- **EXPLAIN the importance of having access to accurate construction cost data to overcome the real-world challenges of the construction industry.**

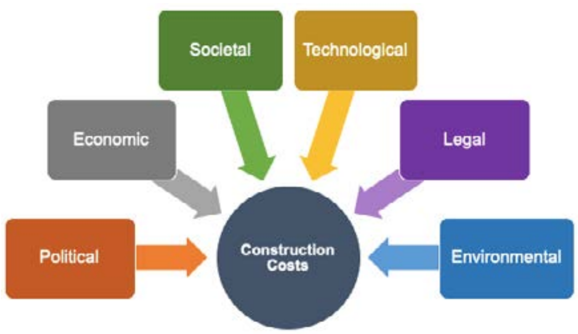
Over those months and years, material and labor costs can swing dramatically. What if the architect and the building team could conceptualize the build costs down to the square foot, up to three years into the future? That's the essential promise of *predictive cost data*, an increasingly used approach for embarking on construction projects with tomorrow's data in hand today. It requires a database, first, and some existing cost data archives total more than 10 billion data points across 15 years [link] from project fillings, public government indexes, and indexes from private sources such as Moody's. This is truly *Big Data*, to which data scientists apply rigorous statistical analysis and sophisticated algorithms for predicting future material and labor costs. Thorough back-testing determines the efficacy of the predictive extrapolations; those that prove accurate to a maximum error rate of less than 3% would be considered highly effective — and therefore serve the AEC project team's needs most effectively.

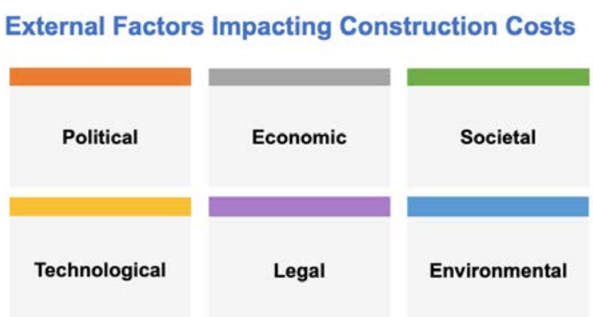
Before getting predictive, however, accuracy is the initial goal for all architects in estimating project costs. Precision is critical for ensuring that designs align with budgets and exceed client expectations — so to achieve high levels of confidence, access to accurate construction cost data is key. An accessible database of trustworthy current and predictive data allows project teams to quickly assemble substantiated pricing metrics for new jobs, realistic estimates, and region-appropriate cost evaluations.

For materials such as steel, recent tarriffs can affect metal roofing costs, above, as well as the prices for light-gauge steel framing members, as for this greenhouse construction project, below. (images courtesy Gordian)

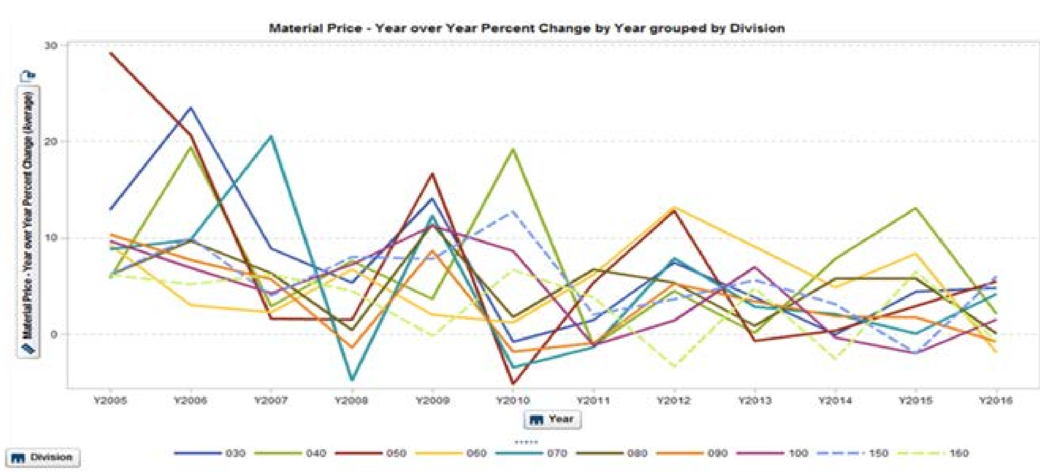


Growth in urban markets is one factor that contributes to material price volatility. (courtesy Gordian)





As estimate level of precision increases it becomes more detailed, with more unknown factors eliminated and a better understanding of the varied factors affecting final cost, including economic, political and environmental inputs. (courtesy Gordian)

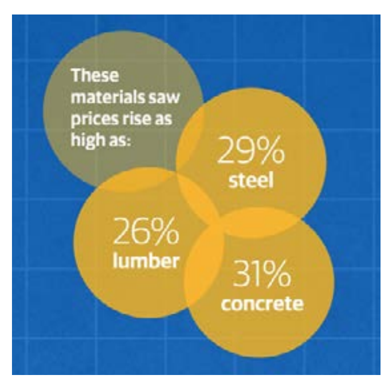


Material cost volatility, as shown in this steel material "basket index," underscores how predictive data can help mitigate the impact of market swings on building projects. (courtesy Gordian)

Savvy architects also rely on accurate cost data to make the most of their project budgets. Employing reliable pricing information helps design teams find viable, value-creating alternatives; integrating predictive cost data into the design process helps keep today's plans in line with tomorrow's financial realities. When it comes to maximizing project budgets, accurate data makes all the difference, says David Morgareidge, the Dallas-based predictive analytics director at engineering firm Jacobs and the multidisciplinary architecture firm Page.

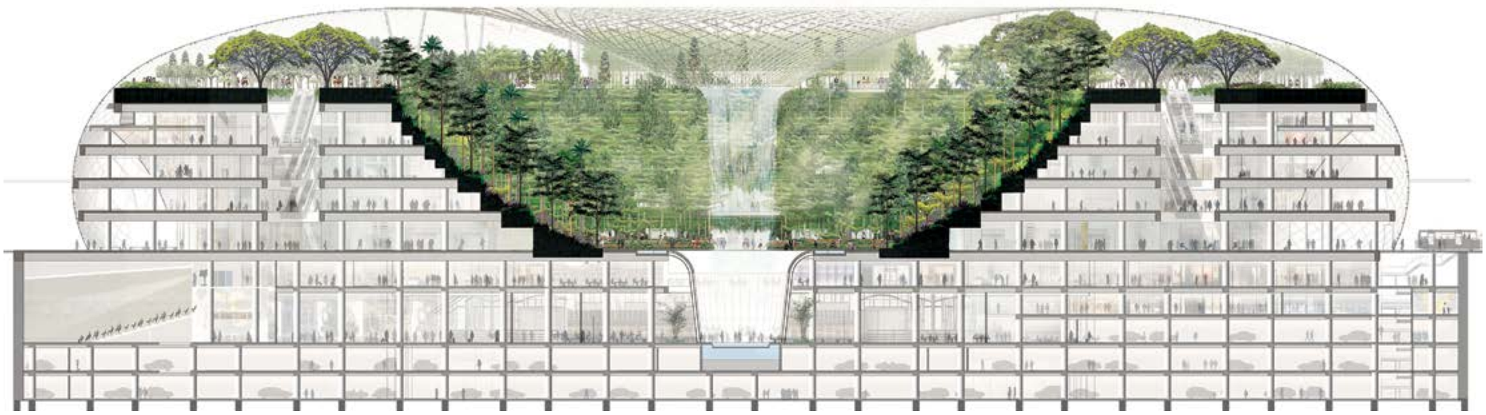
"Traditional approaches have limited capability to explore alternatives due to cost and schedule constraints imposed by the delivery methodology itself," Morgareidge told *DesignIntelligence* recently. "In a predictive analytics project, the virtual, digital model, coupled with optimization engines, allow one to evaluate hundreds or thousands of alternatives, and to then rank order the results based on the client's performance criteria, to find the truly optimal solution in a quantitative, objective, data-driven way. Traditional approaches cannot do that."

Three examples of how volatility can exacerbate materials prices, with swings as high as over 30% for concrete. (courtesy Gordian)



Accurate Construction Cost Data: Advantages

The concept of data-driven design has gained a following. The book *Data-Driven Design and Construction*, authored by Randy Deutsch and published by Wiley in 2015, presented the case for using data better and more integrally today. Even before that, the main benefit of incorporating accurate cost data had been called, "designing with value in mind," as James Brown, a principal of QAE, wrote in the seminal book, *Value Engineering: A Blueprint*. More than simply achieving "more for less," says Brown, VE provides a way to achieve "the lowest cost without sacrificing reliability."

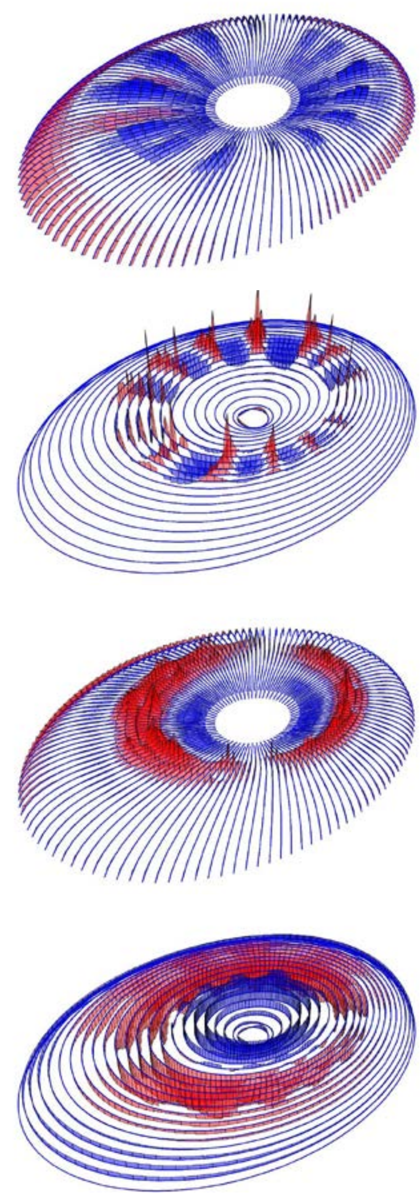


"Data-driven building design feeds into desired outcomes, including successful, innovative designs and real client satisfaction," says William Pollak, CEO of Gordian, a provider of facility and construction cost data. "Today's data offerings and predictive estimating abilities accommodate construction lifecycle considerations in ways that were only imagined a decade ago. Behind today's expectation for accuracy is data."

If data is vital to reliable and precise cost estimating, where do architects and project teams begin? Services available include longstanding, dependable databases drawn continuously from thousands of sources. One of them has a construction cost database with more than 85,000 labor, material and equipment costs, making it a robust source with tens of thousands of viable alternatives that can be placed in assembly units. Those units can be swapped out in square foot models, making for more realistic rough order-of-magnitude (ROM) estimates, which describe the valuation of project's level of effort and cost to complete.

An estimator tool and application, which may be helpful in ROM estimating. (courtesy DeWalt)

ROM estimates are colloquially called "ballpark" budgets used to provide a starting estimate for a project to move forward, says Amiryar Hassib, a lean-agile project management professional with McLean, Va.-bsed MITRE. This top-down estimation approach uses previous expert knowledge and experience and is fairly quickly created, with relatively large variances of -50% to +50%. (Compare the ROM estimates to a *definitive estimate*, with its typical variance of -5% to +10%.)



Data-driven design is trending in the engineering of many complex building projects, including the new Jewel Changi Airport in Singapore. The engineering team from BuroHappold working for Sadie Architects employed multiple types of data analysis to reduce costs of steel structure fabrication and erection for this exceptionally complex, toroidal grid shell structure. (images courtesy Safdie Architects)

With more insights than teams working with traditional data forecasting, architects and project teams using data-driven design estimating can leverage empirical evidence, macroeconomics and data mining – the latest in "big data" innovations. (image courtesy Jubilee House)

Yet the accuracy of the underlying data and predictive capabilities from using an authoritative source can make a big difference: The greater level of detail from accurate data "shows that our company understands the details of the designs we do and the impacts that the choices made during the initial design as estimated through final design" says architect John Bolton of the A/E firm CTA [to confirm: not from the firm Hafer of Evansville, Ind.]. In addition, better data sources allow for faster pricing and more valid estimating outcomes. Larger data resources also can provide region-specific costs and more granular levels of detail, which are critical to accuracy as well as streamlining project delivery and, ultimately, meeting owner expectations. In addition to larger data resources, architects and AEC teams should look for:

- **Data sources organized in logical, accessible formats for all phases of a project.**
- **Construction cost estimating tools to supplement in-house data.**

Good construction cost estimators develop a system of forms and procedures that "meet the unique requirements of each project and are understood and accessible by others" on the building team, according to a NIBS Whole Building Design Guide (WBDG) article by authors including William Manfredonia, CPE, of the cost estimating firm Cost Calculations, Inc. Estimates may be prepared in the UniFormat estimating system, for example, so that building system and material alternatives may be quickly analyzed. "This system should provide the ability to define material, labor-hour and equipment-hour quantities required for the project," adds Manfredonia. "Material, labor and equipment unit costs are then applied to the quantities as developed in the quantity survey." In the final summaries, the estimate adds factors for overhead and profit, escalation and contingency.

Methods for Successful Data Use

According to experienced architects and professional estimators, the idea of data-driven design implies the application of accurate cost data into *formats that organize the data for each project phase*. Basically, as the project develops, the needs of the owner and architect cause the estimate preparation and information to evolve, with increasing degrees of data granularity as the design process develops. Manfredonia adds that various elements of the design will achieve increased completeness at different times – for example, the mechanical system design may only be at 50% complete while the architectural design might be at 90%.

In all cases, as an estimate level increases it becomes more detailed, with more unknown factors eliminated and more useful information added. Corresponding to the building design and construction process, the following levels of cost estimate are achieved:

- **Level 1:** ROM or rough order-of-magnitude estimate, typical for the feasibility and project pre-planning phases. Costs per square foot are estimated based on the project's location and siting, general functions, schematic layout and ballpark size.
- **Level 2:** With a better definition of the work scope, the conceptual or schematic design phase allows for the Level 2 estimate, which is considered as likely to be contained within budget.
- **Level 3:** In the Design Development (DD) phase, cost estimates reflect a delimited scope and finalized design with material selections complete. "Estimates at this phase may be used for value engineering applications before the completion of specifications and design drawings," according to Manfredonia.
- **Level 4:** Before the distribution of project documentation for bidding purposes, a highly accurate Level 4 cost estimate can be made with Construction Documents (CDs) that are 90% complete or better.
- **Level 5:** To develop probable costs in bid preparations for contract, Bid Phase estimates are valuable for evaluating submittals, subcontractor proposals and change orders.

During each phase, estimates by knowledgeable architects and building teams employ construction cost estimating tools that serve as a supplement to their in-house data. New-generation estimating software, for example, provide cost data packages coupled with customization options to enhance planning, budgeting and estimating. Some online products allow users to create site-specific square foot models based on libraries of existing models that can be customized quickly. Many of the tools are designed for flexibility and productivity gains: Project teams can tag and store frequently used units and assemblies for repeated access, or customize assembly components and square-foot cost models. To report on estimates, some software products offer user-defined report templates for estimates with drag-and-drop report creation.

Data Driven VE

Along with the benefits of cost estimating tools, data-driven design allows for enhanced value and improved building quality. One of the opportunities enabled by data-driven building design is value engineering (VE), which is often misunderstood as a budget-reduction approach or a method leading to loss of quality.

In fact, value engineering is a methodology credited to General Electric's Harry Ehrlicher, Jerry Leftow and Lawrence Miles, who faced extreme shortages of raw materials, quality components and skilled labor due to manufacturing peaks during World War II. The team developed a systematic approach – they called it *value analysis* – to improve the value of goods by considering their specific functions and the resources applied to achieve those functions, which were often expressed as costs, according to Rob Dekkers in the book *Applied Systems Theory*. Alternatives would be considered that could lead to reduced costs, improved performance or better quality.

The practice has spread since Miles et al. pioneered the approach, and today value engineering is used in various industries to solve problems, identify and eliminate unwanted costs, and improve function and quality. "The main benefit is that **the value of products increases** when they meet performance requirements at a lower cost," says Gordian's Pollak. "Whether a building design team wants to substitute one material for another, consider alternative building methods or limit a project's environmental impact, the process of value engineering remains generally consistent."

Project teams and skilled design professionals often find the biggest benefit of VE in value is large systems—HVAC, lighting and electrical distribution, for example. The VE analysis often uncovers reasons to spend more on higher-performing systems because they can significantly reduce maintenance costs over a building lifespan. Through the use of VE alongside life-cycle cost analysis (LCA), quantitative input from the client group's maintenance and operations team can deduce the long-term cost implications of major systems, which informs the VE decision making.

A project team meeting at Spacesmith, a leader in architecture and interior design projects internationally with an understanding of business and operational considerations for their clients. (courtesy Spacesmith)

Overall, value engineering demands that architects and building teams view a project with a wider lens and scrutinize materials, plans and processes to identify cost-effective alternatives to that meet the requirements of a project. In order to effectively value engineer, design professionals need to know where costs lie – and this requires one or more sources of accurate cost data from a reliable industry expert. Deep resources of construction cost data, such as from RSMeans data, provide robust construction cost databases with cost information on tens of thousands of variables including labor, materials and equipment types. Those cost alternatives can be placed in *assembly units*, which can be easily swapped out in *square foot models*, making for highly realistic ROM estimates.

According to experts in VE for construction applications, the six steps of VE are:

- **Step 1:** Identify the material makeup of a project or system.
- **Step 2:** Analyze the functions of those elements. In other words, what does it do?
- **Step 3:** Develop alternative solutions for delivering those functions. Are there other approaches or ways to do this?
- **Step 4:** Assess the alternative solutions. Can any proposed alternative still deliver the performance and experience the owner demands?
- **Step 5:** Allocate costs to the alternative solutions.
- **Step 6:** Develop the alternatives with the highest likelihood of success. The key question is, what will do the best job for the longest time?

Using these techniques and processes associated with VE help ensure successful project outcomes. VE has been shown to maximize client budgets, routing resources to other facets of the project or lowering final costs. It is also a way to ensure performance meets expectations for the long term.

Photos of the construction process for College & Crown, an award-winning multifamily building with concrete, wood and steel elements — and integrated facade artworks by the achitects — in New Haven, Conn. (courtesy Svigals + Partners)

Market Challenges for Project Costs

There are other issues that arise during building project delivery that complicate everyday decision-making, not to mention VE. Making project estimating highly challenging, for example, is the *price volatility* associated with commodities, construction materials, labor and more. According to the U.S. Bureau of Labor Statistics (BLS), for example, material costs rose 4.8% between 2016 and 2017, a dramatic and unexpected swing. From 2017 to 2018, the construction information firm FMI forecast that spending would increase 6% to $1.3 trillion. Yet global productivity has remained essentially flat for the last half century, as noted in a 2016 World Economic Forum report. "Today, rising material and supply prices present a multidimensional problem for the construction industry," says Gordian's Pollak. "This is especially with continued demand for materials and uncertainty surrounding potential tariffs and international import changes."

In fact, the geopolitics of *tariffs and international trade* have impacted the hyperlocal economics of U.S. building teams, though thankfully only a limited extent, in most cases. "While certain events such as tariffs directly affect raw material prices, the correlation to construction materials is not always realized dollar for dollar in a sort of chain reaction within a certain period of time," says Tim Duggan, Vice President of Data and Analytics at Gordian. For example, when the United States put into effect a tariff in March of 2002, the first signs of contractor counter prices increasing emerged around the first and second quarter of 2004 – almost two years later. Other factors came into play, as U.S. domestic steel mills during that time reprogrammed their raw material intake from new steel to recycled steel, minimizing the impact of imported product.

That being said, when the cost of construction actually does change, it is important to have access to the latest information in pricing, says Duggan. More pronounced and direct effects on cost volatility can come from external factors such as fires, energy prices, and overall market uncertainty. Looking at examples of cost fluctuations in steel, concrete, and lumber provides some perspective

Flooding is one of the weather-related challenges for building teams in creating accurate estimates. Above, flooding in a municipal lot (courtesy Gordian) and below, a historic image of flooding at the legislative building in Manitoba, Canada. (courtesy city of Winnipeg)

for architects and building teams seeking more accurate, data-driven design information:

1. Concrete. An index of concrete materials by RSMeans data combining hot-mix asphaltic concrete, concrete block and ready-mix concrete shows that prices are fairly predictable in terms of cost increases, especially as compared to steel. From late 2014 to mid-2018, for example, the average yearly cost of concrete increased about 3% per year. But the climb is unsteady, Duggan cautions: Mild swings can affect a project's concrete budget. Conclusion? Concrete prices experience light fluctuations during the year, but consistently end up with a price increase of nearly three percent.

2. Steel. The concrete index is far less volatile than its steel counterpart, says Matthew Kelliher-Gibson, an expert in data science. "Last year, we started tracking steel costs in anticipation of announced steel tariffs," he explains. "Steel's long-term cost pattern of steady 1% growth is punctuated by wild quarter-to-quarter volatility, but the tariffs dashed the old pattern." In the second quarter of 2018 alone, he says, the value of the index grew an astonishing 12%, and for the first time since 2014, steel costs increased for consecutive quarters. The market had shifted into uncharted territory. Yet later cost increases were lower, and year-to-date prices were equal to steel's historic growth plus the 25 percent tariff.

3. Wood. The value of the wood, on the other hand, remains fairly flat for significant periods and grows steadily over time. However it has relatively large spikes from time to time, such as in the third quarter of 2017, when the index value jumped dramatically – for wood, that is, but not as compared to concrete or steel. Instead, wood exhibits other variability that building teams should recognize. For example, region matters: the cost of wood in the West is consistently lower than in other districts. Overall, however, the cost of wood is as steady and reliable as the performance of the material itself.

Other Cost Volatility Factors – and Solutions

In addition to the steel and aluminum tariffs, which have made national headlines recently, other factors affect the costs of construction materials and building projects. Examples include fires and wildfires, changing energy prices, and certain kinds of market uncertainty, such as economic or political instability. Being able to predict and consider VE alternatives for projects in these situations is essential to keeping budgets on target.

As a stark example, the thousands of people who lost their homes or businesses in record Midwestern flooding or the fires that swept through Northern California faced unusual difficulties in the renovation or rebuilding of their structures. According to the *Sacramento Bee*, "Labor costs, a shortage of contractors, insurance uncertainties and safety concerns could all delay or drive up the price of rebuilding," not just for those affected by the disasters but also for anyone building in the region. "Labor shortages are a particular headache," according to the news report.

Energy volatility can affect construction budgets, as can the raw materials market, which is highly dependent on energy prices and remains volatile both in the United States and abroad, according to Thomas Industry Update. "Issues on the supply side and rapid changes in the global economy — spurred by rising demand and consumption rates in emerging markets — are generating uncertainty, as well as being major factors in the volatility of raw materials prices," said the report. This uncertainty can contribute to price increases, as the typical original equipment manufacturer (OEM) bears 15% to 20% of its total costs from raw materials.

To protect their building projects and client groups from excessive cost volatility, architects and building teams are evaluating their conceptual designs to understand what could happen if the construction timeline is extended due to approvals, permitting, weather challenges or other unforeseen circumstances. Projecting costs in this way is complicated and requires forecasting tools based on very large datasets. For more accurate planning and budgeting, many building teams are supplementing (or replacing) their traditional forecasting data with *predictive data*, which allows design professionals can consider all future factors at play in a given region, including local labor rates and material costs. These factors can be considered in budgeting and cost estimating processes.

Predictive cost data differs from traditional econometric forecasts primarily because they don't rely on macroeconomic theory and instead derive exclusively from data-driven, empirical evidence. The evidence draws on extensive exploratory data analysis and pattern-seeking visualizations of historical cost data with economic and market indicators, according to Dr. Edward Leamer, a UCLA professor of global economics and management. Only economic indicators that have "proven themselves" in exploratory analysis become candidates for model development, testing, validation and predictive cost estimates. In addition, predictive cost data employs *data mining* techniques to improve traditional econometric modeling practices. Since the 1990s, this family of processes and analyses has evolved to benefit from increases in computing power, data visualization techniques and updated statistic procedures to reveal patterns and drivers of construction material and labor cost changes.

Measures of these drivers and their relationships to each other and to construction costs, along with their associated lead or lag times, provide building teams with very more robust way to predict cost impacts. In fact, the ability to employ predictive data dramatically improves the team's ability to account for real market conditions – such as the amount of construction as compared to labor availability — and commodity price impacts on material costs. Predictive knowledge is critical to keeping designs in line with budgets. Predictive data helps ensure not only that project costs are forecasted accurately, but also that clients will have more confidence in their project teams and their building designs and the people behind them.

Estimates and External Influences

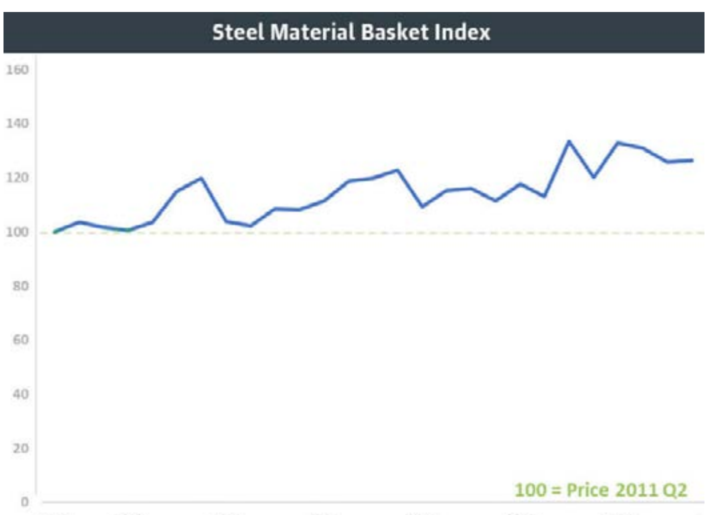
Given the potential for volatility and the capability of predictive data to help mitigate the impact of market swings on building projects, it helps to look at specific examples where cost data is used effectively – and where it falls short. Some of these examples help demonstrate how cost data without considerations of external influence negatively impact project outcomes.

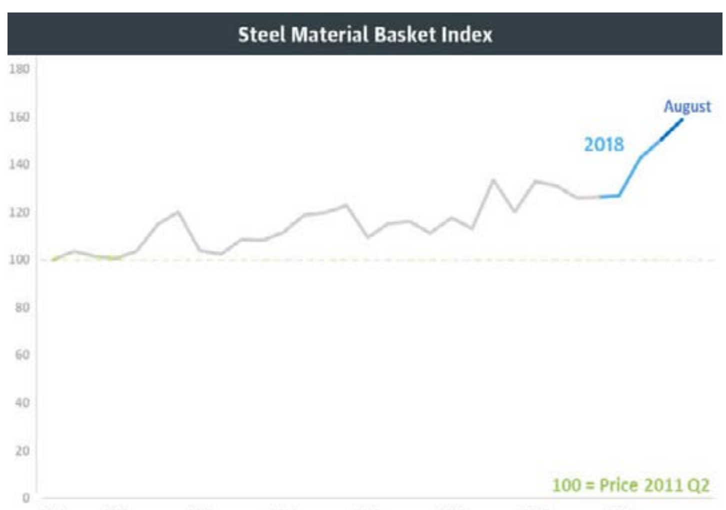
One experienced CM professional, Christopher Gartner, P.E., the CEO of Gartner & Associates, works to assemble project teams and facilitate construction phase work, including preparing plans with budgets running the entire life of the projects. Cost estimates for all change orders are also part of the deliverables. Historical data offers a solid starting point for Gartner, but he also incorporates other data sources to ensure truly reliable estimates, in particular to reduce errors caused through omission.

"For every project, we analyze every detail so that the owner groups have accurate, thorough cost data to inform their decisions," says Gartner. During initial budgeting, the firm uses square foot costs from a source also providing the building components required. This helps ensure accurate assemblies-level cost estimates, with all required tasks or materials identified and included. From there, unit cost estimates are created to hone in on itemized costing and to detail out specific aspects of the project to increase accuracy. The same data sources are used during change orders.

As example of the data-driven design applications, Gartner points to some of the firm's 400-plus projects over the last three decades – all using the same cost data source. For example, his team shepherded the $35 million renovation of the World War II-era California Building, an elegant mixed-use facility in New Orleans converted to retail and luxury residential spaces. The building team's project estimate came in less than 4% of the final cost. In another project in Austin, Texas, the Gartner cost estimate came within 0.5% percent of the contractor's bid, winning the trust of this major client. Localized and accurate construction cost data was also essential to mitigating risk and remaining a dependable CM.

Basket indexes show the prices of materials, and can be used to
(courtesy Gordian)





An example of the data-driven design applications, the $35 million renovation of the World War II-era California Building in New Orleans, had a project estimate came in less than 4% of the final cost. (photo by Rafał Konieczny, Krakers)

In another example, the benefits of accurate cost data include accounting for externals, future-proofing of designs, and allowing for early-phase experimentation. In this case, the architecture and engineering (A/E) firm CTA has developed its own in-house software backed by a subscription data service. The firm is able to generate a fine level of detail to reliably show clients the possibility of potential cost impacts versus a lump-sum number, according to the architect Bolton. The data-driven approach also lays a foundation for VE, including itemized material, labor, equipment and productivity costs. With the cost data available, CTA estimates generally fall within 3% to 8% of contractor estimates in design-build project delivery.

The cost estimates and key data also serve as a reference point throughout the construction lifecycle. "The data source allows the design team to incorporate costs into a project as we understand the impacts, so we are able to coordinate with contractors to achieve the best costs for the client," says Bolton.

As seen in these case studies, predictive capabilities and predictive data offer a vital toolset for project cost estimating and control. With more insights than teams working with traditional data forecasting, architects and project teams using predictive data benefit from a data-driven design phase leveraging empirical evidence, macroeconomics and data mining – the latest in "big data" innovations. If data-driven design means adapting to real market conditions and significant price impacts, it would appear to be a powerful tool in creating responsive, successful architecture.

Accurate Cost Data: Contingency vs. Escalation

The terms "escalation" and "design contingency" are invoked often in the estimating discussion, but they are distinct concepts and not well understood.

In broad terms, escalation describes what will happen, which contingencies describe what *might* happen.

Contingencies are included to account for estimating inaccuracy caused by quantitative errors — take-offs — and qualitative errors that arise from the design process and the contractor's risk assumptions. Those variances can be caused by hidden site conditions or new regulations put in place during the project period, for example. Or it can be caused by the "scope creep" that often arises in the architecture and engineering processes.

Other persistent factors, such as inflation and reduced material supply during busy construction cycles, are described as escalation. If the project is estimated for bids one year but ends up taking bids two years later, expect a 24-month escalation penalty to be reflected in the final numbers.

The good news is that escalation ends the minute the project is awarded.