5 WAYS TECHNOLOGY IS SHIFTING THE STRUCTURAL ENGINEERING INDUSTRY IN THE NEXT 5 YEARS

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INTRODUCTION

Structural and civil engineering are the oldest forms of engineering and some of the earliest professions. They were developed with the rise of ancient civilizations thousands of years ago. As buildings became bigger and more complex, the profession became more advanced and enabled the construction of complicated and sustainable structures. However, structural engineering is now seeing tremendous developments in the fields of information technology, computational methods, visualization technologies, and artificial intelligence.

The basic practice of structural engineering was the same until the rise of finite element analysis-based computing around 50 years ago. FEM (or FEA) software allows structural engineers to accurately predict internal forces, deformations, and stresses in complex structures. One of the first building designs to use finite element analysis in a significant way was the roof of the Sydney Opera House during the 1960s and 1970s.

The American Society of Civil Engineers (ASCE) (2007) has defined future civil engineers in its 2025 vision as master planners, designers, constructors, operators of society's economic and social engine, innovators, and integrators of ideas and technology across the public, private, and academic sectors.

FIVE WAYS TECHNOLOGY IS SHIFTING THE STRUCTURAL ENGINEERING INDUSTRY

Structural engineering is taking advantage of technology to enable new approaches to structural design.

These innovations are providing society with more efficient, lower cost designs and sustainable construction. If your organization has not begun implementing these innovative methods, you may find yourself falling behind competitors in the coming years.

Building Information Modeling (BIM)

The construction industry utilizes design programs to model complex geometry, to perform advanced structural analysis (nonlinear, push over, modal …), and to schedule construction planning. However, and from a digital point of view, the field overall is relatively poorly connected through trades, majors, and platforms. The use of BIM, which is an IT-enabled tool, improves computational methods and control processes and increases collaboration in construction projects. This is game-changing in the architecture, engineering, and construction (AEC) industry and will drive the evolution of this industry for the future.

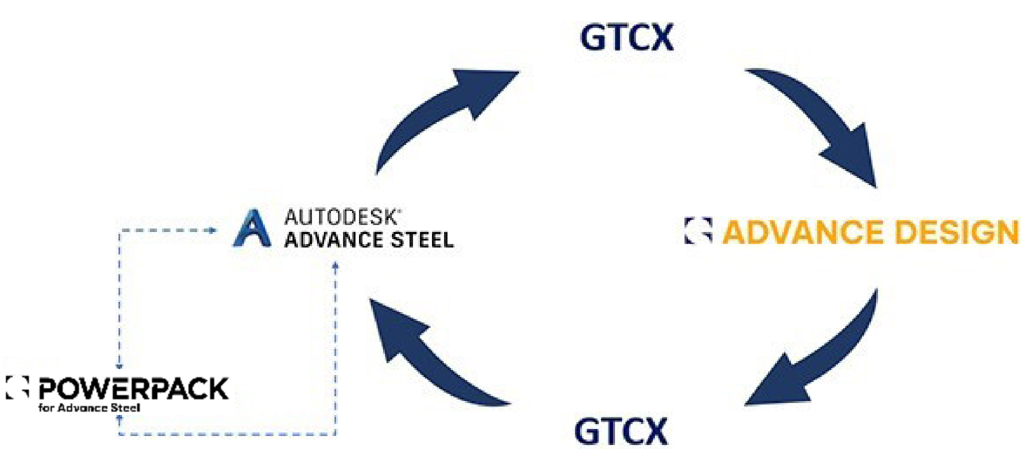
BIM enables the creation of 3D content and has become the standard of the industry. The benefits of adopting BIM are:

- ☑ simplification and acceleration of work, organization of information throughout the lifecycle of the building,
- ☑ improved cooperation of individual professions,
- ☑ data exchange between software tools and platforms,
- ☑ elimination of errors in design and transparency in construction costs,
- ☑ perfect support for clash detection and problem-solving during design,
- ☑ ability to study alternative solutions on one model to obtain better and optimized construction solutions.

On the other hand, the assumption that all design teams are providing high-quality 3D content that can be used robustly for construction is not always true. There are a few reasons for this:

- Without a clear understanding of BIM, many companies are unable to fully achieve BIM potential or implement BIM in their building lifecycle.
- There is a difference between modeling building components in BIM for general coordination versus modeling with the precision needed for an electronic deliverable. Small imperfections in model geometry can create significant problems if that information is relied upon by a contractor.
- Often, only primary building components are modeled in the design phase, with no integration of secondary members and no detailed modeling of complex member connections.
- BIM programs that are used for design are often different from the programs used by subcontractors for fabrication.
- An investment in software and training is needed to adopt BIM.

GRAITEC, a software publisher specialized in the AEC industry, offers a solution that can streamline data exchanges among several construction professionals. For example, it allows structural engineers and steel detailers to exchange data/3D models even if they are not using the same platforms. With Powerpack, GRAITEC enhances the link between Autodesk Advance Steel (used by the detailer) and Advance Design (used by structural engineers) – an exclusive file format, **GTCX**, is used to import-export-synchronize data between the two applications. This BIM workflow allows a complete data exchange back and forth from the design of the structure, through the detailing, to the final fabrication, allowing all the stakeholders to collaborate.



GRAITEC also offers a complete data exchange with REVIT; it enables intelligent model-based workflows for engineers and construction professionals. Advance Design acts as a BIM platform and guarantees the continuity of geometric and analytical data through model transfers all along the design cycle.

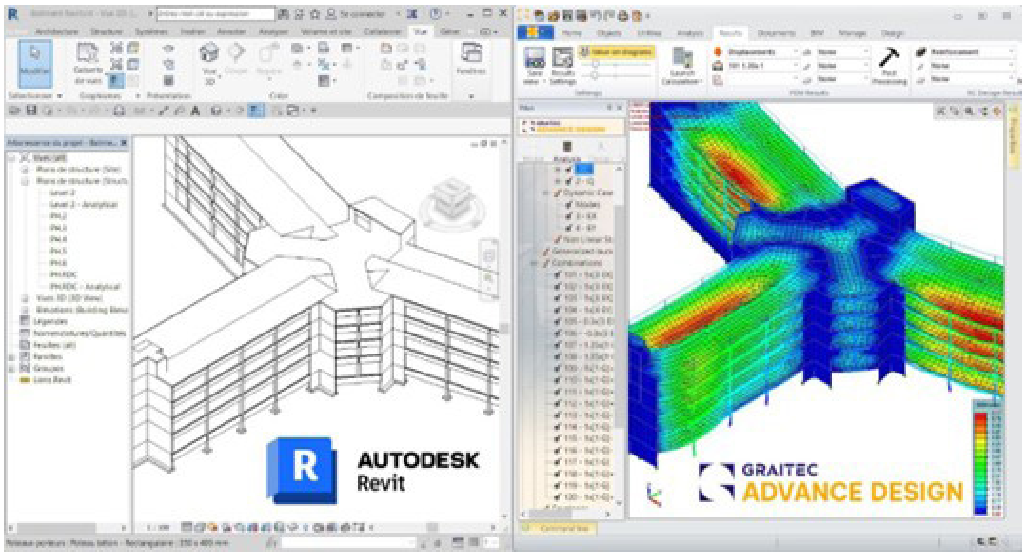


Figure 2: Example of BIM connectivity between AUTODESK REVIT and GRAITEC Advance Design

Analysis results are also stored in the digital model and are part of the BIM process. For instance, they can be used to start a rebar design or a steel connection process directly from Revit. These options open new disruptive opportunities.

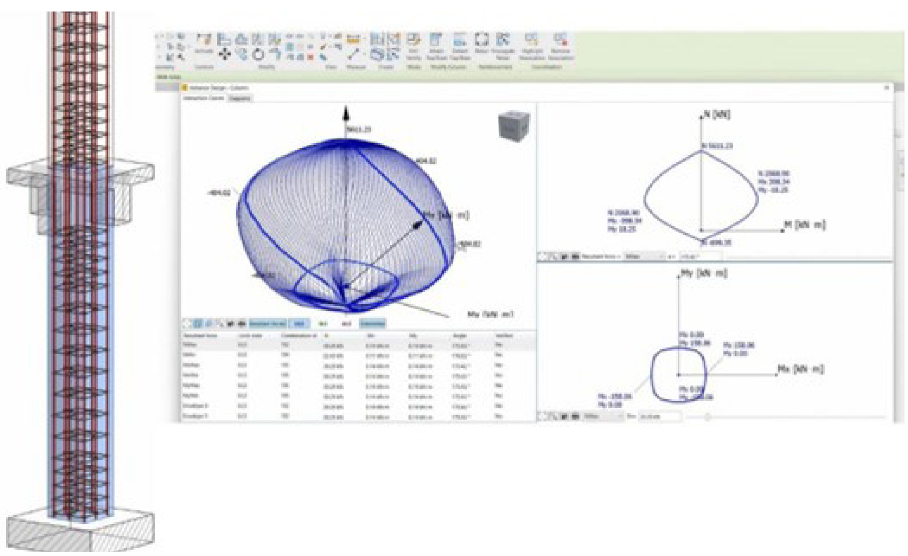


Figure 3: POWERPACK for REVIT enables in REVIT "Concrete Design Extension" powered by Advance Design

Cloud Based Collaboration / Cloud Computing

In typical client-server computing, a network-friendly client version of the application/software is required on client computers that utilize the system's memory and CPU for processing. Cloud computing differs from the classic client- server model by providing applications from a server that are executed and managed by a client's web browser, with no installed client version of an application required. This centralization operation gives cloud service providers complete control over the versions of the browser-based software and applications provided to clients, which cancels the necessity for version upgrades or license management on individual client computing systems. As compared to traditional techniques, cloud computing is a more flexible, mobile, highly automative, and cost-effective technique.

The aim of a cloud based platform for structural analysis software is to build a flexible and better equipped environment for engineers to design and construct buildings using high performance computing. Another benefit the cloud can bring to structural engineering is web APIs (Application Programming Interface): a way to tell structural analysis and design programs what to do by writing software code.

Figure 4: Cloud based collaboration and computing

Combining an API with the "anywhere access" philosophy of the cloud is a powerful tool for running structural analysis and design automatically, wherever you are in the world. A simple program can take data from your PC, send it to the cloud, and return structural analysis and design results back to you. Some software editors have also suggested mobile applications for visualization of structural analysis results, which give structural engineers and onsite technicians better visibility into the project.

Artificial Intelligence, Machine Learning, and Deep Learning

Artificial intelligence (AI), machine learning (ML), and deep learning (DL) are relatively new techniques capable of providing the engineering community with affordable automated solutions compared to those obtained through traditional manual methods.

Artificial intelligence is a computational method that attempts to simulate human cognition capability to solve engineering problems. Machine learning uses computer algorithms for automatic improvement through experience, developing computer programs that can access data and using them to auto-learn. Machine learning in construction may improve safety, productivity, and quality.

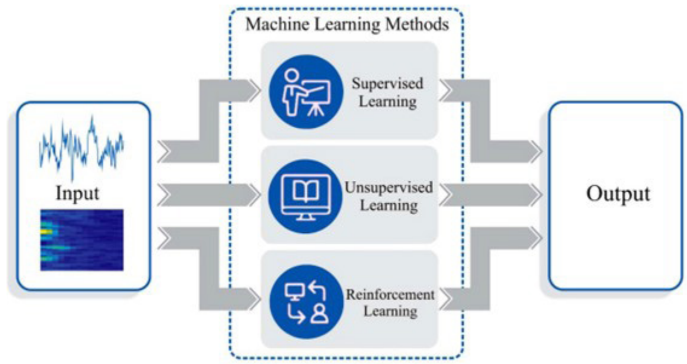


Figure 5: Components of a Machine Learning system

With increasing complexities in new structural systems, analysis procedures, and modeling, the need for quick prior knowledge about pre-sizing and pre-defining the initial geometry and configuration of structural members is also increasing. A relatively quick and reliable estimation of the previous parameters, as well as key response parameters, can greatly facilitate the preliminary design and feasibility of a project. Artificial intelligence and machine learning can greatly help in developing innovative solutions.

The rationalization of the design process of building structures, within a structural optimization framework, has usually been separated into three components:

- topology, which involves decisions on the number and connectivity of members, usually done without optimizing the connection itself;
- shape, which involves decisions related to the location of elements and the layout of joints;
- sizing, which involves defining member cross sections.

We may find a lot of interesting approaches using AI in the structural engineering field.

Another application for AI is Structural Health Monitoring (SHM), which continues to be the subject of intensive research in structural engineering. It can be divided into two categories:

- image-based SHM employing the computer vision technology;
- vibration signal-based SHM based on the signals obtained during dynamic events.

The latter can be divided into two general approaches: parametric system identification (modal parameters identification) and non-parametric system identification. ML algorithms have been used extensively in both types of SHM.

Performance-Based Design in Seismic, Wind, and Fire

Performance-based design (PBD) is the design methodology of the future. It is the concept of starting with the end goal as the primary goal (i.e., the performance level), and then using analysis, simulation, and testing to demonstrate that a structure will meet that performance level.

The focus of building codes and norms is on perspective design in order to provide safe buildings and life-safety performance. This approach involves strict requirements on structural design (materials, strength, and detailing). This prescriptive approach is strict, so it does not allow structural engineers to take varying design paths to attain code-level performance, nor does it distinguish between higher levels of performance.

Performance-based design is an approach to obtain:

- Buildings that perform better than the prescriptively designed ones.
- Buildings that don't meet code but can be shown to be equivalent to prescriptively-designed buildings.

PBD is not an answer for every building, but for the right projects—complex, tall, iconic, or important—PBD is the right solution.

Concerning seismic design, this approach allows the design team to work together to determine the appropriate levels of ground motion and performance objectives for the building and the non-structural components in order to meet the client's expectations. The PBD seismic process is illustrated in Figure 6.

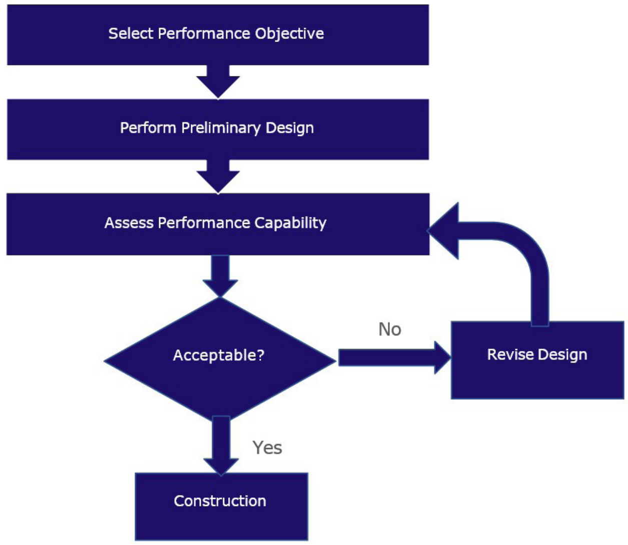


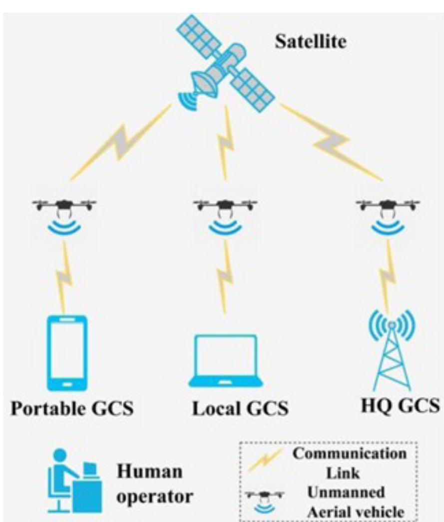
Figure 6: the PBD seismic process

Currently, the PBD methodology has been extensively applied to the seismic loads and seismic design of structures. However, attempts are being made to extend this methodology for wind loading as well.

Regarding wind loads, in 2019 the American Society of Civil Engineers released a pre-standard for PBD Wind. For the evaluation of safety, this alternative approach is based on performance level, building drift, occupant comfort, and response to extreme wind.

PBD for fire is in its infancy stage. Design of fire performance is a wide domain.

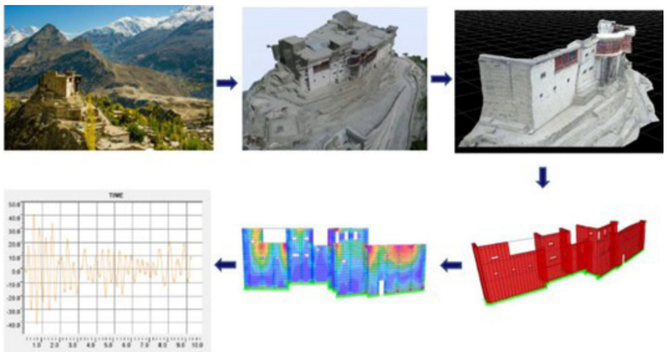
Unmanned Aerial Vehicles (UAVs) – Drones



The application of unmanned aerial vehicles (UAVs), also known as drones, has increased recently in several fields. They include engineering, construction, image and video, rescue, military, medical, delivery, hidden area exploration, miscellaneous domains monitoring, wireless communication, and aerial surveillance.

Figure 7: Architecture of UAV system

The construction industry can take advantage of these revolutionary technologies in most of the practical aspects: pre-planning, detailed survey and mapping of job sites, construction process monitoring, post-build checks, and sales and marketing. For example, surveyors can use drones as a real-time tool to monitor the progress of the site and compare it to their program. Contractors can use the data acquired from drones to track progress and prepare an as-built record.



(a) Automated computer modeling and structural analysis of structures using drone images

More recently, 3D scanning of a construction site can be used to build a 3D model using photogrammetry techniques. This so-called “drone model” can be converted to a BIM model, and therefore to an FEM model, and analyzed after adding corresponding loading (refer to Figure 8).

(b) Smart monitoring of progress in construction projects using drones

Figure 8: Applications of drone and image processing-based technologies in structural engineering

On the other hand, the drone model can be compared to the BIM model at various construction stages to monitor construction progress. This process can be used to control construction progress, planning, and costs, as well as to generate reports and verify bills. This fully automated system can significantly reduce time and cost compared to traditional construction monitoring and reporting procedures.

CONCLUSION

During the last few decades, new technologies are changing the engineering industry. The impact of this progression is obvious and evident in structural engineering, where modern techniques and devices are improving structural modeling, design, and results. Structural engineers were, in fact, some of the pioneers and originators of applications of computing systems and methods (e.g., finite element method). They are invited nowadays to embrace modernized computing techniques and devices, not only to provide answers to the ever increasing number and nature of problems, but also to keep pace with the booming development around us.

References:

Ansah R H and Sorooshian S (2017). Effect of lean tools to control external environment risks of construction projects; Sustain. Cities Soc. 32 348–356.

H. Salehi and R. Burgueño (2018). Emerging artificial intelligence methods in structural engineering.

Havelia, P. (2016). A Ground Structure Method to Optimize Topology and Sizing of Steel Frame Structures to Minimize Material, Fabrication and Erection Cost; Ph.D. thesis, Stanford, CA: Stanford University.

J.P. Amezquita-Sanchez et al./Scientia Iranica, Transactions A: Civil Engineering 27 (2020); 2645-2656.

Málaga-Chuquitaype C. (2022). Machine Learning in Structural Design: An Opinionated Review; Frontiers in Built Environment.

N. ANWAR, F.A. NAJAM. How Latest Technological Advancements are Transforming the Structural Engineering Profession; ICEC-2019.

Z. ZHENGUANG, Application of BIM Technology in the Construction Phase of Steel Structure Engineering; IOP – 2021.

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