

Analytical-Physical Modeling and Interoperability Propels BIM Advancements

A Bentley White Paper

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Structural Engineering for the Physical World

Advances in Building Information Modeling (BIM)

As BIM becomes pervasive in all types of engineering projects, structural engineers are adjusting their workflows and software tools to adapt to the challenges and opportunities that this technology brings. But what should structural engineers keep doing, and what should they do differently? And, most importantly, what outcomes and benefits can they expect if they are able to take full advantage of a structural BIM workflow? This white paper examines approaches to structural modeling that can yield significant benefits to structural engineering teams. New technologies, such as Bentley Systems' STAAD CONNECT Edition structural analysis and design application, implements these approaches. As a result, engineers can maintain model quality while responding to changes and consider more design alternatives in a timely fashion.

Trends in Structural BIM

Every day the number of structural designs originating from a BIM model increases. McGraw-Hill reports that over the past decade the number of engineering companies using BIM has grown to exceed 65 percent of firms. According to the report, this represents a 300 percent increase. This pervasive use of BIM could be considered a two-edged sword to the structural engineering industry. The software allows for a more significant exploration of design alternatives with immersive visualization to aid in decision making, but it also enables more exotic architectural designs requiring more complex structural idealization. The unique project architectures place greater burden on the structural engineer to consider intricate geometries and ever increasing environmental and performance demands.

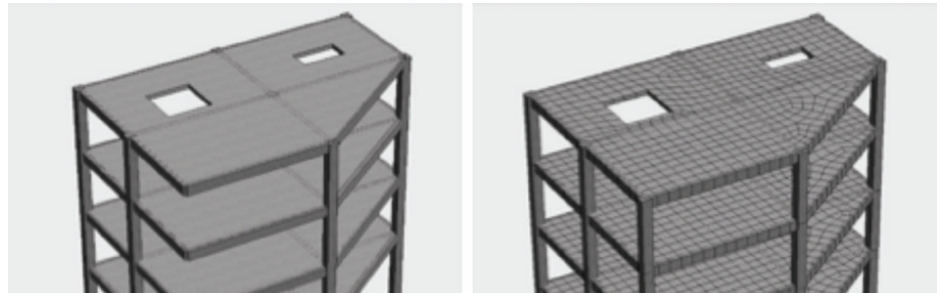


BIM facilitates more complex architectural designs requiring improved structural interoperability.

¹ The Business Value of BIM in North America, Multi-year trend analysis (2007-2012), McGraw Hill Construction.

As the level of detail in the BIM models has increased, the need for automation to produce accurate idealizations of the structural analysis models is imperative for engineers to stay competitive. Without effective automation, the engineer's time will be consumed in the transformation of the physical architectural vision into the analytical structural idealization required to accurately determine structural demands and behavior.

During the past decade, there have been significant interoperability advancements among structural analysis and design software tools to address the transformation of increasingly complex physical architectural and structural designs into an analytical idealized (finite element) structure. As all BIM applications allow for modeling of discrete parts of a structure, our structural applications must have a fundamental concept of a physical part that is more readily mapped to the architectural models in geometry, material, and loads.



Physical-to-finite element discretization in STAAD.Pro CONNECT Edition.

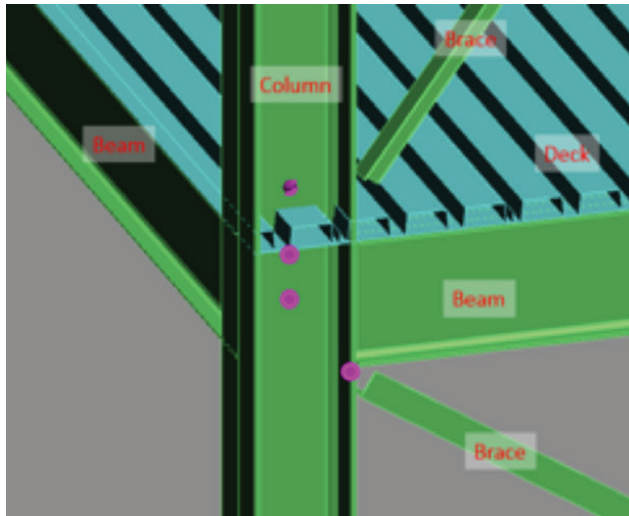
Engineers have used the finite element method (FEM) to simulate the behavior of structures subject to loading for over half a century. But along with its flexibility and utility FEM also brings the overhead of generating and managing the finite element mesh.

The responsibility of transforming this 'physical model' into a 'finite element model' rests entirely on the structural analysis software and enables engineers to spend more time understanding structural behavior or alternate designs and less time on creating or manipulating finite element objects.

What is Analytical-Physical Modeling in a Structural Context?

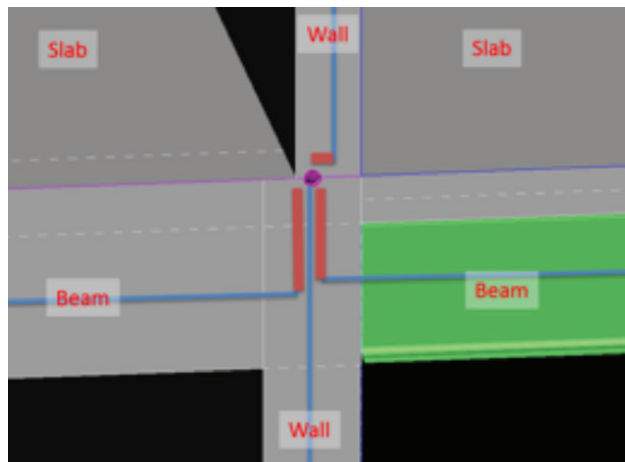
Engineers have used the finite element method (FEM) to simulate the behavior of structures subject to loading for over half a century. But along with its flexibility and utility FEM also brings the overhead of generating and managing the finite element mesh. Significant time is spent on meshing and re-meshing, particularly when architectural changes lead to many revisions of a structural model

For beam-column models, this overhead is managed and partially reduced by using single FEM elements to represent entire 'physical' objects. Even in this case however, beam-girder intersections, connecting braces, haunches, and other details add complexity to the production of the idealized finite element model and retaining fidelity with the physical BIM model.



Domain logic is needed to produce appropriate finite element idealization of a physical model.

This issue is exacerbated when plate elements are added for walls, slabs, or other in-plane components. The model complexity increases significantly and mesh management becomes a major overhead as compatibility in the finite element mesh between intersecting planar and linear elements, and differences in physical and finite element geometry, becomes a primary concern. This is significantly more complex in 3D models with physical walls, slabs, and beams intersecting at various angles, in which case meshing becomes a time-consuming, complex task to do manually.



Analytical-Physical model at intersection of multiple offset slabs, walls, beams.

The Analytical-Physical model is more precisely a physical representation of the finite element model. This Analytical-Physical model is still an idealization of the precise physical model created using BIM applications. However, it is at a level of granularity of the physical objects, not the nodes, boundary conditions, nor 1D or 2D finite elements.

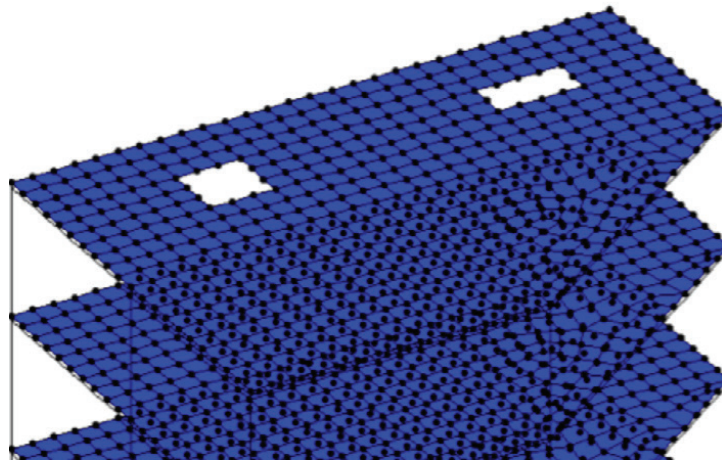
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By turning over much of the responsibility of the discretization (converting the Analytical-Physical objects into finite element entities) to the structural software, the engineer can more efficiently adapt to changes in the model and its loading as members, surfaces, and loads no longer need to be discretized to apply to the finite element model.

Bentley's STAAD.Pro structural analysis application incorporates these philosophies to support a more physical workflow in which changes are easier to make. The newly released STAAD.Pro CONNECT Edition includes a new physical modeling environment for the creation and maintenance of an Analytical-Physical model. The user can model in the physical modeler or use the traditional finite element modeling approach. When the physical modeler approach is used, STAAD.Pro automates the process to idealize the structure and loads into a finite element model. In this workflow, geometric changes are made only to the Analytical-Physical model and the finite element model is regenerated as needed as the physical model evolves.

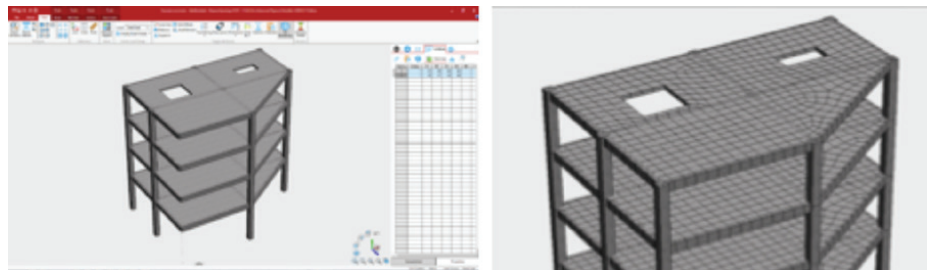
The user may choose at any point to disconnect the finite element model from the physical model and proceed using the traditional STAAD.Pro finite element modeling approach. This best-of-both-worlds approach allows engineers to take advantage of new BIM workflow capabilities without losing the flexibility to manipulate the finite element model as they traditionally have.

Particularly where walls and slabs are considered, the physical modeling approach provides not just BIM workflow improvements, but also modeling efficiency advantages over previous versions of STAAD.Pro. When surface or plate elements in the STAAD.Pro model are discretized into a finite element mesh, the original object from which the finite elements were created is lost. Any further manipulation of the surface or plate must be done on the individual finite elements from that point forward. Suppose a user wants to then add or move openings to a floor slab. To do this using STAAD.Pro's purely finite element workflow, the user would need to tediously manipulate the individual nodes, elements, and loads in the finite element mesh.



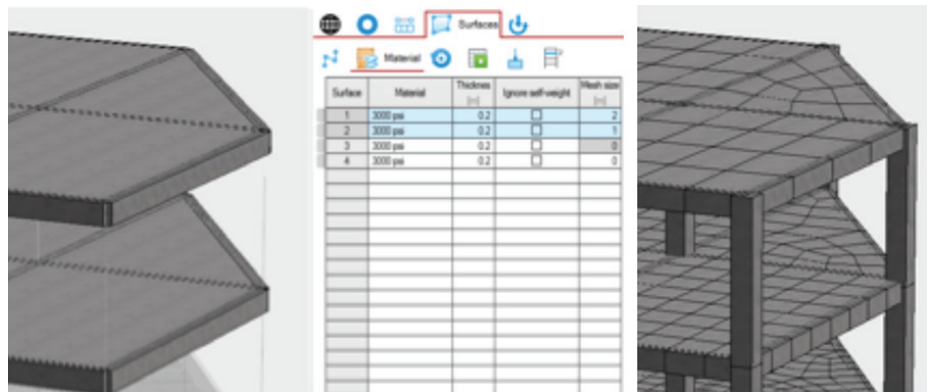
Revising openings in finite element models can be cumbersome.

STAAD.Pro's physical modeling workflow overcomes this limitation. Changes are made to the physical floor slab and the finite element mesh is then regenerated. Openings can be created by specifying new nodes anywhere on the floor. The opening is defined as an array of nodes forming the opening boundary. The opening can be repositioned or resized simply by revising the corresponding node coordinates. Once openings are added, the finite element model is recreated, with the physical model as a constraint, by simply regenerating the analytical model.



STAAD.Pro CONNECT Edition Physical Modeler and automated finite element mesh.

The size and configuration (triangular vs. quadrangular elements) of the finite element mesh can be specified in STAAD.Pro Physical Modeler, where a global setting is available. Further, mesh size can be controlled using the Mesh Size parameter associated with each physical surface element. A different value can be assigned for each element.



Mesh size of finite element model controlled through STAAD.Pro CONNECT Edition Physical Modeler.

Benefits of the Analytical-Physical Model

A significant advantage of working on an Analytical-Physical model relates to the speed and accuracy with which changes can be made, whether manually or through a BIM model. In STAAD.Pro CONNECT Edition Physical Modeler for example, surface and line loads are no longer divided and applied to individual finite element members, but can be associated with the supporting physical members to automatically adjust as the tributary areas or member geometries change.

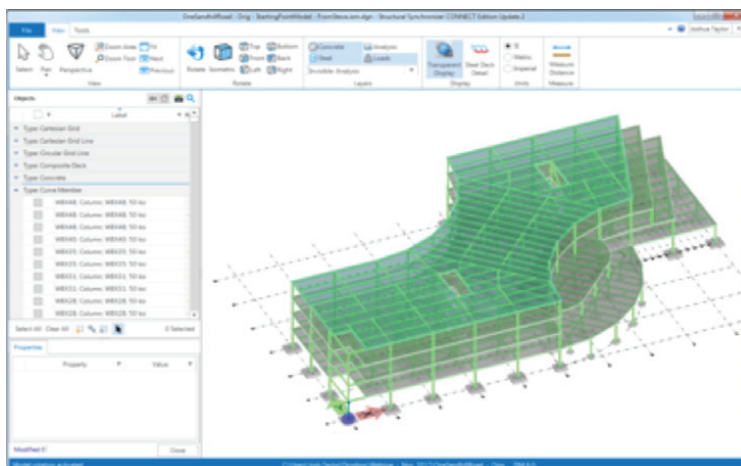
Another significant benefit of operating on a physical structural model is the close, but not exact, correlation to the physical BIM model. This close correlation allows for a significantly higher level of fidelity on interoperability of information between the structural software and the physical BIM model. But it is not a silver bullet.

Challenges of BIM Interoperability

Fundamental data constructs differ among software applications. For example, one application's "slab openings" are another application's "egress shaft." While, fundamentally, the physical manifestation is the same, the need to transform between an "opening on a single physical slab" to a construct of an "extruded negative space through multiple stories," is non-trivial.

Another common challenge related to physical versus finite element approaches in software products is how they handle certain member profiles (shapes). Besides different section naming conventions that must be addressed by the engineer, how applications handle built-up shapes also varies. A double-angle in one application might be two individual angles in another.

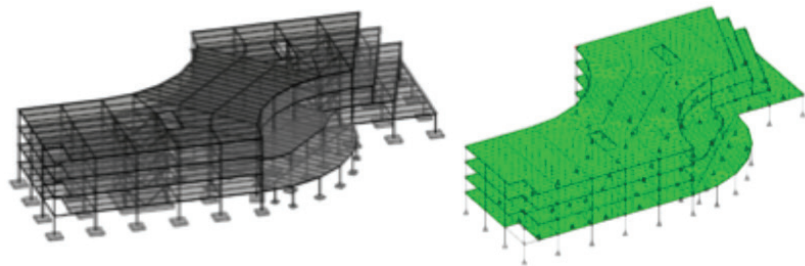
These are just some examples of analytical to physical to finite-element model issues that must be understood and addressed through the interoperability process. These issues will likely continue for as long as there are different software solutions whose competitive advantages lie in how their data is organized and modeled. These differences in structural solutions are a positive and should be understood in that light when data transformation issues arise.



Bentley's Integrated Structural Modeling (ISM) interface for managing interoperability.

The technology through which interoperability occurs is also critical to the fidelity of the interoperability. Open standards such as IFC provide a compelling archive and aggregation/viewing format, but special flavors of IFC for specific workflows make higher fidelity interoperability a challenge. Common platforms such as Bentley's Integrated Structural Modeling (ISM) provide a level of control through the data exchange by identifying changes to a common model. This allows the engineer to control the changes that are communicated between applications and allows applications to utilize or contribute only that information in the common model it cares about. In some cases, a direct integration between two products is facilitated and can provide a high level of fidelity, but will require certain versions of both products be available on the same machine and requires continuous maintenance of point-to-point links by vendors.

ISM presents a BIM use case of significance to the new STAAD.Pro CONNECT Edition. While STAAD.Pro's legacy link with ISM continues to be available, STAAD.Pro CONNECT Edition now offers a link between the Physical Modeler and ISM. This new Analytical-Physical based link supports the exchange of two-dimensional structural elements, such as slabs and walls, which is not present in previous releases. This expands the breadth of information STAAD.Pro can exchange with BIM applications such as AECOsim Building Designer, ProStructures, Revit Structure, and Tekla Structures.



A Revit™ model (left) converted into STAAD.Pro using ISM-based interoperability.

BIM models can be read into STAAD.Pro Physical Modeler, and vice-versa. Furthermore, ISM allows changes made to element sizes and configurations in STAAD.Pro Physical Modeler, including surface elements, to be updated into other consuming applications. The STAAD.Pro link with BIM applications can be live throughout the course of a project and can be utilized as a powerful means of managing revisions.

Regardless of the technology used to facilitate the interoperability, the construct of an Analytical-Physical model in structural software has been the biggest enabler of effective data exchange between physical BIM models and structural analysis and design solutions.

The increasing adoption of BIM as the method of choice for conceptual and detailed architectural design has resulted in more elaborate and complex designs than ever before. With this complexity, there is a need for more effective and automated BIM to structural analysis interoperability. The fundamental construct that is enabling this BIM revolution is the ability of structural analysis applications, such as STAAD.Pro CONNECT Edition, to robustly transform the real world physical designs into idealized Analytical-Physical models, without the need to discretize (mesh) structural elements during interoperability. These Analytical-Physical models allow for faster adjustments to geometry and loading enabling more efficient exploration and optimization of design alternatives.

BIM interoperability is further enhanced using standards such as IFC or Bentley's Integrated Structural Modeling (ISM) workflow that provides design history and change management control during the design process. Structural analysis and design software has evolved significantly in the past decade to enable more robust and automated interoperability to keep up with the increasing complexity of designs enabled through the BIM revolution.

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