Linking Scanned Data to Simulation

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Researchers use terrestrial laser scans to develop solid models for accurate structural simulation of buildings.

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As simulation usage grows in architectural design, engineering teams must develop low-cost, high-accuracy solutions to generate solid models of buildings for city-scale modeling. Recent developments in remote sensing technology offer rapid, high-density 3-D data collection options — specifically terrestrial laser scanning (TLS), which directs a beam over terrain or building surfaces. Availability of this data created the opportunity to develop technology that automatically reconstructs the solid models. Such a tool would make the simulation process automatic, seamless and robust. It would rule out reliance on measured drawings or photographs to construct the exterior geometry of the model; it would avoid possible data corruption from using a CAD-based program as an intermediary.

Thus the School of Civil, Structural and Environmental Engineering, University College in Dublin, Ireland, developed the FacadeVoxel algorithm to automatically generate solid models of masonry building facades from TLS data. Engineers can load the geometric model directly into ANSYS structural mechanics software to set up finite element analysis for a wide variety of civil engineering applications. The effect of tunneling on surface structures is a timely issue, so the university chose this as an example of how users can apply the algorithm to structural simulation.

The FacadeVoxel algorithm overcomes a major challenge in reconstructing a solid model from TLS data — to accurately recreate appropriate geometry and opening-based stiffness without any user intervention. The software uses a two-step voxelization-based approach for characterization and conversion: The general boundaries of the building are detected, and then major features are discerned and checked. This leads to the successful identification of real openings, such as glass doors and windows, and the filling of unintentional holes in the model caused by sparse or missing data. The approach is data driven, independent of architectural grammars or other techniques that require prior knowledge of local construction styles and practices.

For example, a 19.4 m high by 17.0 m long brick facade in Dublin was scanned from two positions with TLS (Fig. 1). The scans were merged and automatically resampled using proprietary software to generate a random density of 400 pts/m^2 (Fig. 2). This point cloud data set was then processed with the FacadeVoxel algorithm to automatically convert the laser-scanning point cloud data into a solid model compatible with ANSYS structural mechanics (Fig. 3).

When compared to measured drawings provided by an independent surveyor, the solid model's resulting geometry was very close to that of the actual building. Solid model overall dimensions were within 1 percent of measurements, while the opening ratio (opening area over facade area), which controls the building's stiffness, was within 3 percent. The opening dimensions were generated with no

Fig. 1. Terrestrial laser point cloud image of facade

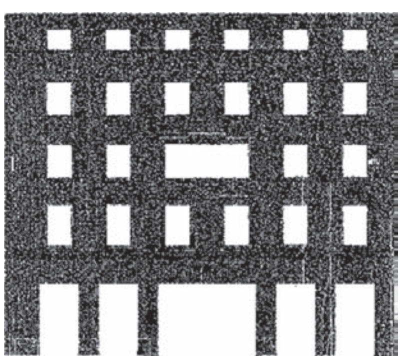

Fig. 2. Input data of resampled point cloud

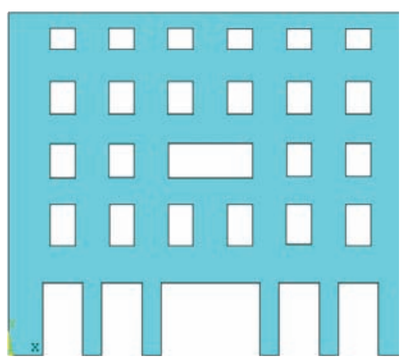

Fig. 3. Solid model automatically reconstructed with FacadeVoxel software

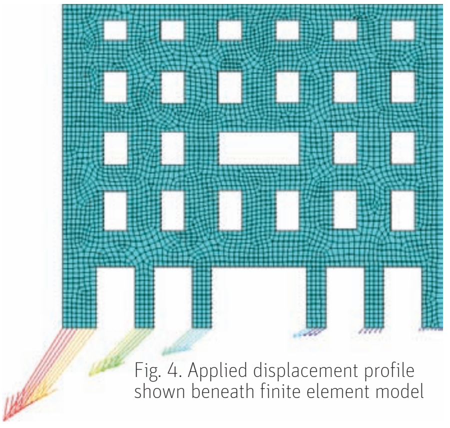

Fig. 4. Applied displacement profile shown beneath finite element model

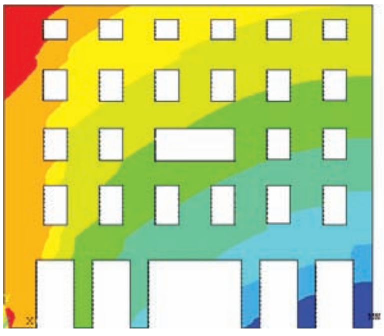

Fig. 5. Nodal displacements of building when subjected to tunnel-induced foundation settlement

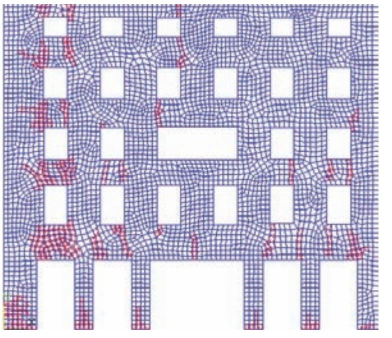

Fig. 6. Resulting cracking patterns from nodal displacements

more than 10 mm average absolute error. For a medium-sized building facade, processing takes about 20 minutes to generate a solid model from 350K points on a standard PC — with no user input required. To begin simulation, the model is imported into ANSYS software from FacadeVoxel.

In the sample test, the model was subjected to an adjacent tunneling subsidence profile (Fig. 4), and the results in terms of displacements (Fig. 5) and cracking-based damage patterns (Fig. 6) were highly realistic. Researchers obtained these results from nonlinear analysis of the building facade's solid model (Fig. 3), in which a macro-modeling strategy — used to obtain general behavior of large-scale masonry structures instead of applying micro modeling, which models interface behavior between brick and mortar joints — modeled the building wall using the SOLID65 element in the ANSYS Mechanical APDL product. Applying the William and Warnke (WW) failure criterion for compression and Drucker–Prager (DP) yield criterion for tension enabled the team to model masonry behavior. The WW failure criterion provides a tension cutoff for the DP yield criterion. The team used a sample material representing weak masonry properties for analysis.

Elastic Behavior	1260 MPa of Young's modulus and 0.07 of Poisson's ratio
Plastic Behavior	4.1/0.07 MPa of compressive/tensile strength, 1.07 MPa of internal cohesion, 35 degrees of internal friction angle and 10 degrees of dilatancy angle

Material settings for tunneling subsidence profile

Researchers conducted the analysis under self-weight loading and imposed displacements, the latter directly applied to nodes on the bottom of the model (Fig.4).

The resulting small, geometric discrepancies in solid models from the FacadeVoxel algorithm were tested for influence on structural response. The team compared structural results based on auto-generated solid models to those derived from CAD drawings created from measured drawings of actual buildings submitted to Dublin City Council as part of the planning permit process. Three structures (two small, one large) were tested with various materials and loading rates. In the example, the difference of averaged absolute errors from the two typical results was less than 5 mm for maximum deformation of the opening span; they resulted in a final difference of only about 1 mm for maximum crack width. In the tunneling community, these results are within the standard margin of error; therefore, a structural analysis based on the solid model can provide sufficiently accurate results to evaluate building damage due to tunnel-induced ground movements.

Currently, the algorithm is configured for two-dimensional use; it is most effective with rectilinear forms. Work is under way to extend the capabilities to three-dimensional analysis and to refine feature detection algorithms for curved forms. Recent successes are based on stationary terrestrial units, as the density of even the best aerial laser scanning data set is not yet adequate to automatically model building facades, with data of sufficient quality available only for horizontal surfaces such as roofs and streets. To date, the FacadeVoxel algorithm has yet to be tried on truck-mounted TLS, but the team plans to investigate this in the future.

The combination of the FacadeVoxel algorithm and ANSYS structural simulation provides a promising solution for reconstructing solid models of building structures from TLS data at a city scale. ■

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Reference

http://www.ucd.ie/eacollege/csee/staffmembers/debralaefer/research/