Designing for People

By Lachmi Khemlani, Founder and Editor, AECbytes

What Really Matters?

The mantra in any field of human endeavor is "faster, cheaper, and better," and this is true of our physical infrastructure as well. The AEC industry is constantly striving to design, build, and operate buildings more efficiently and cost effectively, thereby heeding the faster-and-cheaper call. But how about better?

In fact, it can be argued that better trumps faster as well as cheaper. After all, what is the point of creating a cheaper building faster if it does not work well for its occupants?

And, that being the case, what is it that makes a "better" building?

Evaluating for "Goodness"

While there are several aspects of a building that determine how "good" it is and how well it works, the following would inarguably be at the top of the list:

- Structure: Is the building safe to inhabit? Does it make the most efficient use of materials? Is it designed in a manner that enhances rather than impedes spatial quality?
- Habitability: Does the building accommodate all the necessary functions? Can people find their way around easily? Are they able to exit safely in case of an emergency? Are there hold ups, delays, or congestion? Are all the spaces being utilized efficiently?
- Performance: Is the building sustainable? Does it make the most efficient use of resources? Is it physically comfortable for the occupants?

To determine the quality of a proposed design, it needs to be evaluated based on the above criteria. Also, this evaluation can be continuously repeated for subsequent iterations of the design to fine-tune its quality and make it as best as possible.

Using Technology to Improve Quality

Architects and engineers typically rely on established rules of thumb in their professional practice to design buildings that are structurally sound and ergonomically suitable (see Figure 1). There are also broad guidelines on aspects such as building shape, orientation, materials, glazing, and so on for energy efficiency, which they can follow to design better-performing buildings.

Figure 1. Images courtesy of (from left to right) Johnson Pilton Walker, Voyants Solutions Private Limited, SimpsonHaugh and Partners, and AG5.

However, now that almost all design is done on computers using software applications, the ability to evaluate a potential design to improve its quality can be done much more easily and quickly.

For a building design to be evaluated using computational software, it must first and foremost, be represented computationally in a format that can be understood and interpreted by software applications that work with building designs. This is what is referred to as a "model." To evaluate the quality of a design computationally, the model needs to be simulated to determine how it would perform in real life. The results of the simulation can be analyzed, and the analysis then forms the basis for the evaluation. This "Model > Simulate > Analyze > Evaluate" process can be repeated iteratively to refine the design until it satisfies the evaluation criteria that have been targeted for it.

Building information modeling (BIM) gives designers the ability to computationally evaluate potential building designs to improve their quality a lot easier, since the BIM model of a building, by its very definition, represents it using building elements rather than generic geometric elements.

Improving Habitability

Of the top three aspects to evaluate the quality of a building design that were highlighted earlier, structure and performance have already become well established in the building industry, served by a plethora of sophisticated computational programs for simulation and analysis that are routinely used as part of the design workflow. However, the evaluation of the habitability aspect of a design has, so far, not become commonplace. In large part, this is due to the lack of applications that could simulate and analyze what is the main currency of such an evaluation—the people who will be inhabiting the space.

This is where LEGION® simulation software becomes so important.

LEGION

LEGION is a leading pedestrian simulation application that is part of Bentley Systems' portfolio of applications for the design, construction, and operations of buildings and infrastructure. Since the launch of LEGION in 2003, some of the world's leading transit organizations have used LEGION to improve pedestrian safety and operational efficiency in train stations, as well as in projects such as airports, stadiums, concert arenas, museums, and so on.

At its most basic, what LEGION does is simulate how people behave and move in spaces, and it follows the same "Model > Simulate > Analyze > Evaluate" sequence discussed earlier.

Modeling

The model for the simulation of people movement in OpenBuildings™ Station Designer includes the definition of the building geometry within which the people will be moving, as well as objects such as ticket machines and turnstiles. In addition, the space can also include movable elements such as signage and barricades, which will impact the movement (Figure 2).

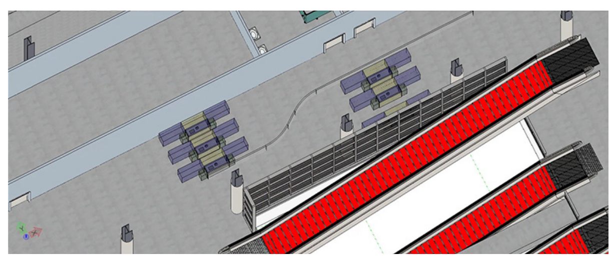

Figure 2. OpenBuildings Station Designer 3D model with ticket gates.

The building geometry can be imported into LEGION from CAD/BIM files of the model. This geometry can come directly in all the leading formats (including DGN, DWG, DXF, IFC, etc.) and from other authoring applications like Revit. The advantage of using a BIM format is that building elements such as walls, doors, columns, and stairs, have already been defined and are identified as such in LEGION. In these "fixed" building elements objects can be added to the model, such as ticket counters, turnstiles, gates, barricades, and signs that will directly impact how people will move within the space. OpenBuildings Station Designer has built-in design component libraries for all of these objects.

LEGION is integrated with OpenBuildings Station Designer, Bentley's multidiscipline BIM application, which will automatically bring the BIM model of the design to be simulated into LEGION. OpenBuildings Station Designer is typically used for designing large projects such as train stations, airports, and stadiums, for which it includes dedicated libraries of components common to these building types such as gates, ticket machines, and turnstiles. However, OpenBuildings Station Designer can be used to design any type of building, allowing its companion LEGION application to be used for improving the design by quickly analyzing how well it works for the movement of people in it (Figure 3).

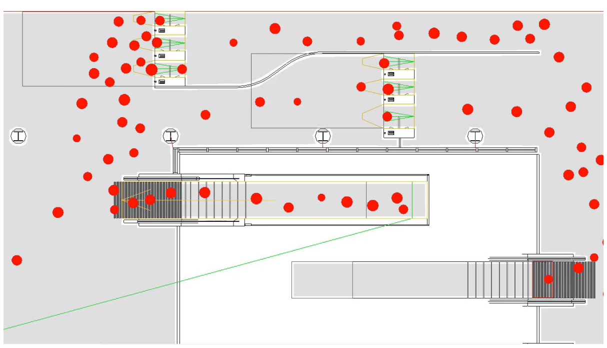

Figure 3. LEGION simulation model of pedestrians through ticket gates (model referenced in Figure 2).

Additional Inputs

In addition to the physical description of the space to be analyzed—which comes from the building model and additional placed components—LEGION requires some additional inputs for its simulation. These include:

- Designation of entrances and exits to define the pedestrian flow, as well as areas where interim activities such as queuing or waiting will occur.
- Definition of any additional objects in the design that could influence movement such as retail stores, kiosks, and food outlets.
- The types of people who will be using the space. LEGION has a large number of varying people profiles differentiated by size, gender, age, walking speed, nationality, and personal space requirements. There are also specific behavior profiles based on the type of project, so, for example, when simulating a train station, people can be tourists (who will tend to linger) or commuters (who are in a rush). They could be carrying luggage (of different sizes) or not. These profiles are based on the systematic observation and measurement of the real-life behavior of a large quantity and variety of people in different contexts, in different cities around the world. Based on the building type and location, the input to the simulation will be a proportion of different types of people. So, for instance, the type and mix of people will be different for a shopping complex as opposed to an airport; similarly, it would be different for a retail complex located in the UK rather than in the US.
- The number of the designated mix of people who will occupy the space for the duration of the simulation, including people who enter the space and those who exit. This input would typically come from historical usage data, anticipated demand, the targeted occupancy count, operational data such as arrival and departure schedules for transit systems, maximum occupancy count for stadiums and concert venues, and so on.

Simulation

All the inputs listed above constitute a "scenario" that will be simulated in LEGION. Different scenarios can be created for testing the design in different demand situations such as for rush hour, time of year, match day (for stadiums), and so on. For a new design, different variations of the floor plan can be simulated to fine-tune its layout, while for existing designs, the testing will be focused more on exploring different placements for movable elements such as barricades and gates. The latter is especially relevant to recent social distancing requirements, where inputs such as the size of the personal bubble can also be modified (Figure 4).

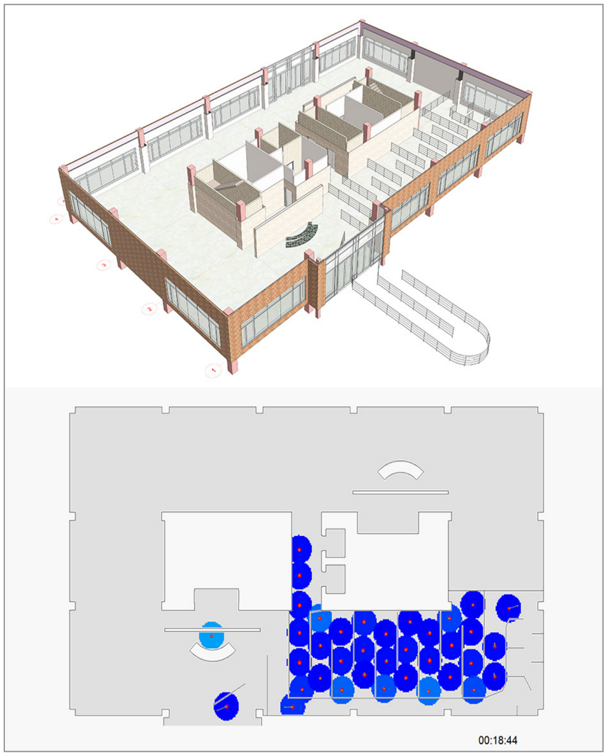

Figure 4. (Top) OpenBuildings Station Designer model post-COVID elevator queuing. (Bottom) LEGION socially distanced heat map elevator queue simulation.

The simulation in LEGION shows the movement of people as they enter the space at the designated entry points (based on the number and frequency specified in the input to the scenario), navigate through it, and leave at the designated exit points. The movement accounts for the behavior of the mix of people that has been specified. This means that rather than treating the entities in the simulation as a homogenous mass—such as the particles in a computational fluid dynamics (CFD) simulation—each pedestrian in the LEGION simulation is modeled as an individual with specific behaviors based on its profile rather than with generic behaviors. Furthermore, the movement pattern of each entity accounts for aspects such as personal space, preferred speed, early detection, and avoiding physical obstacles, maneuvering to avoid collisions, learning from accumulated memories, and other considerations. This level of granularity in the LEGION simulation allows crowd formations and patterns of movement to emerge naturally as it would in real life.

The science behind the pedestrian simulation in LEGION was developed using a comprehensive research program for the study of pedestrian behavior, including video techniques to collect empirical data of pedestrians from venues around the world, which was then systematically analyzed. These results were combined with mathematical modeling to create the simulation engine that drives LEGION. This makes the simulation engine extremely accurate, and it has been validated through independent corroboration from several third parties and a 20-year history being deployed on complex projects all over the world (Figure 5).

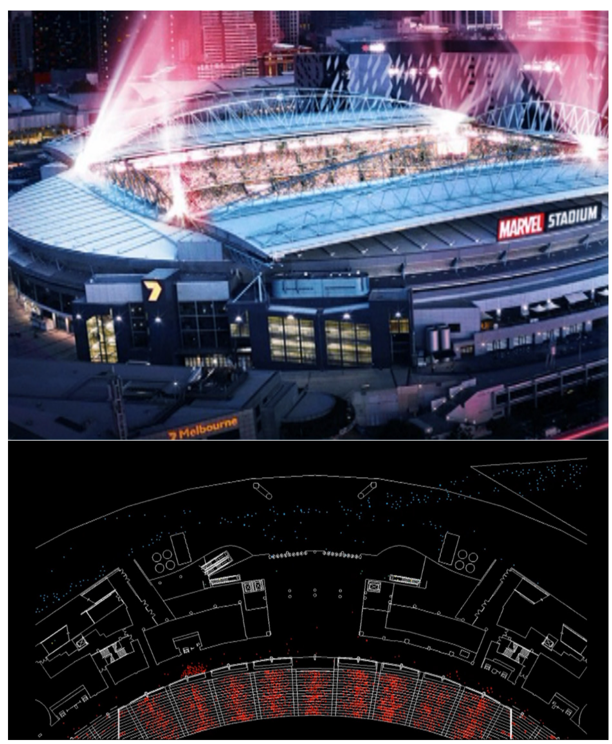

Figure 5. Planning for seating allocation for social distancing as public spaces reopen. Image courtesy of Atkins, part of SNC-Lavalin Group.

Analysis and Evaluation

In addition to the animation showing people as dots on the floor plan (as in Figure 4), the results of a LEGION simulation can also be seen in the form of heat maps, which allow at-a-glance visualization of the areas of over- crowding, congestion, and delays. The simulation results can also be exported as detailed reports showing exact quantitative data for in-depth analysis of key metrics such as counts, flows, distances, densities, journey times, and speeds. And lastly, realistic 3D animations, including those of the people in the simulation, can be created by exporting the simulation results to LumenRT, a Bentley application for high-quality, real-time, photorealistic visualization (Figure 6).

By analyzing the results of the simulation, the design can be evaluated to determine how well it satisfies the habitability requirements of the people who will be using it, including aspects such as space utilization, activity distribution, wayfinding, crowd management, and safety and security. The process would typically involve testing multiple what-if scenarios iteratively, refining the design and/or the layout until the desired results have been achieved.

Implementation

An early example of using LEGION is the Sydney Olympics in 2000, where its crowd simulation capability was used for the transport planning that is critical to the success of such large-scale sporting events. It has, in fact, been used on every Summer Olympic Games since then, and is also frequently used in the design of stadiums and concert venues to plan exit routes that minimize wait times, maximize safety, and avoid congestion (Figure 7).

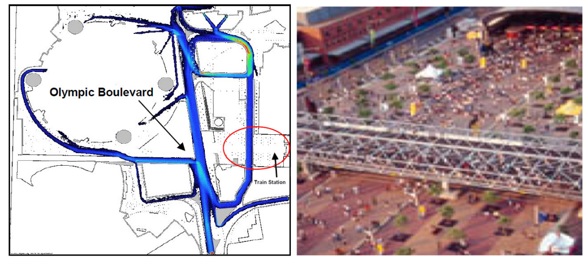

Figure 7. Congestion decreases on Olympic Boulevard with the adoption of the pedestrian footbridge over the rail tracks closing the circulation loop.

Other early adopters of LEGION's people simulation capability are transit systems, which use it extensively to improve pedestrian safety and operational efficiency. Examples include using LEGION in the redesign of London's Waterloo station—which serves 125,000 passengers at its peak—where the owner and infrastructure manager, Network Rail, had to predict passenger movement and ensure that the renovation would be as efficient and safe as possible, including during construction (Figure 8).

Another transit agency that relies heavily on LEGION is the Companhia Paulista de Trens Metropolitanos (CPTM) in São Paulo, Brazil, which operates seven rail lines running across 94 stations and moves an average of 3 million passengers each business day. CPTM used LEGION to analyze passenger flow at 10 existing stations and 12 stations under development and incorporated its findings into day-to-day operations,

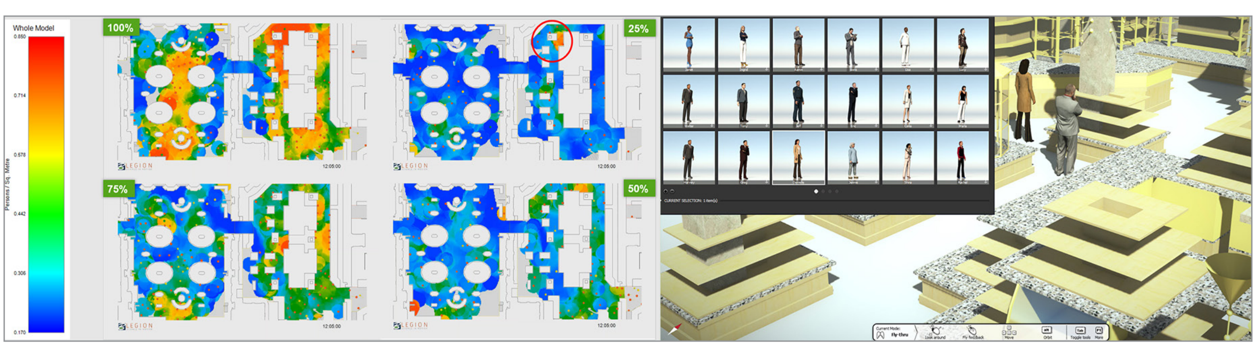

Figure 6. (Left) LEGION heat map simulation scenarios at 100%, 75%, 50%, and 25% occupancy models in a retail department store. (Right) LumenRT model showing socially distanced people placement in a retail department store and characters catalog.

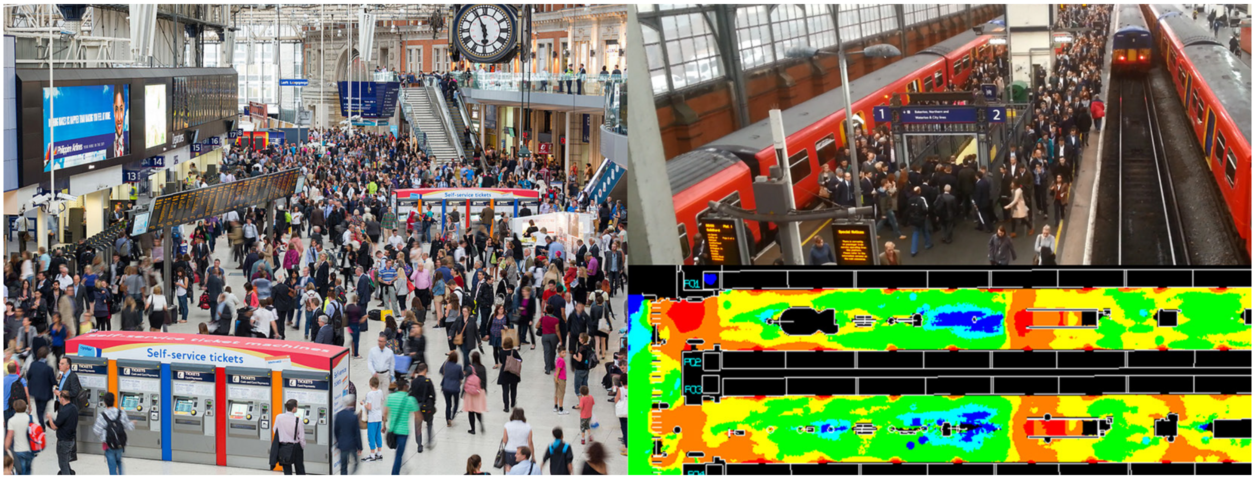

Figure 8. (Left) Waterloo Station Concourse at rush hour. (Right) Waterloo Station Platform LEGION simulation during rush hour. Images courtesy of Network Rail, London.

improving efficiency and passenger experience. CPTM also deployed LEGION during the 2014 FIFA World Cup, which brought thousands of additional passengers into the rail system during the event, concentrated in just a few stations. The simulation capabilities helped CPTM to explore design options to prevent overcrowding and improve passenger flow (Figures 9 and 10).

Figure 9. CPTM uses LEGION to analyze passenger flow across 94 stations and seven rail lines. Image courtesy of Companhia Paulista de Trens Metropolitanos.

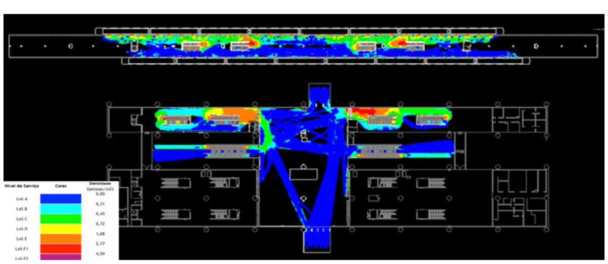

Figure 10. Legion Analyses passenger flow for the 2014 FIFA World Cup. Image courtesy of Companhia Paulista de Trens Metropolitanos (CPTM) in São Paulo, Brazil.

Another example comes from China, where LEGION was used to determine the construction design scheme and draw up the operational management plan for the Fengtai Junction Station, which is set to become one of the most important transportation hubs in Beijing, China. The team from the firm China Architecture Design and Research Group created a LEGION model covering the entire junction and different passenger flow conditions (Figure 11). The model was used to predict the future operation of the junction, based on projected passenger flows and facilitated scheme comparisons that would optimize the spatial layout of the facilities. The model also provided a reference platform for design and construction, improving coordination efficiency among project team members, simplifying decision-making, and keeping the design schedule moving for a 2021 completion.

Conclusion

The ultimate goal in AEC is to design good buildings that work well. While this has historically been accomplished with established rules of thumb, buildings are getting increasingly larger and more complex, making it difficult to rely on rules of thumb alone. Fortunately, we now have an increasing array of computational tools to design better buildings, just as the design of buildings themselves is almost exclusively done on a computer.

While tools for designing buildings that are structurally sound as well as sustainable are readily available and have become an increasingly common part of the design workflow, applications that focus on how well a design works for the people who inhabit it are few and far between, making habitability analysis not as common as it needs to be. However, LEGION is one such application, and it has a long history of being used to improve people movement, safety, and operational efficiency in large projects. Now that it is a part of Bentley Systems and will be more closely integrated with its BIM application, it should enable habitability analysis to become more routinely used in AEC for all kinds of projects, allowing buildings to be designed and operated with a better understanding of how they will be used by the people for whom they are intended.

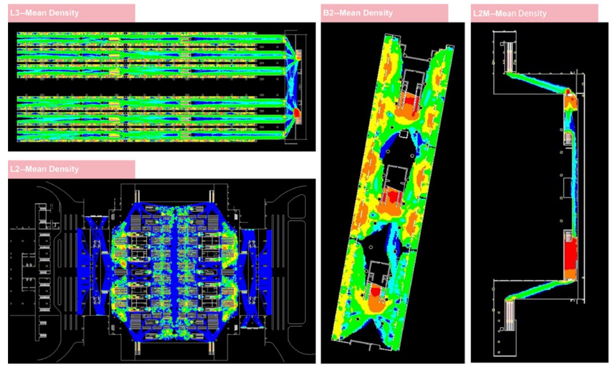

Figure 11. LEGION mean density heat map simulations at Fengtai Junction Station. Image courtesy of China Architecture Design & Research Group.

About the Author

© Lachmi Khemlani is the founder and editor of AECbytes (www.aecbytes.com), a publication that has been researching, analyzing, and reviewing technology products and services for the building industry since 2003. She also consults on the development and implementation of AEC technology, authors research reports and white papers, and serves on juries for technology awards. She has a Ph.D. from UC Berkeley, where she specialized in the application of computing technology to the building industry.

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