INTEGRATING FIRE AS A L

Highlights from a fire design framework project

Matthew Smith and John Gales

OVER THE PAST several years, the consideration of fire to the structural performance of buildings has seen more inclusion in the design process. To this extent, a CISC-ICCA supported research project entitled *Towards a Performance Based Fire Design Framework for Composite Steel Deck Construction in Canada* was undertaken by the authors with the goal of developing a framework for performance-based fire design for composite steel deck structures within Canada.

This applicable research is a collaboration of academic, consultancy, and industry interest. The work is drawing on the lessons learned internationally and the various precedents that have already been established in areas of Canada by others.

This project will assess the required level of competency across all stakeholders; critique the education system that supports performance-based design within Canada (and abroad); perform novel testing of steel sections to begin to quantify the post-fire state that informs business continuity and resiliency of the building; and develop case studies to demonstrate and highlight the range of design options available.

To highlight recent progresses towards these goals, the authors present a short example of novel tools and technologies being employed in this project. These tools specifically deal with the conceptualization of treating fire as a load within the design process.

FIRE AS A LOAD

There has been a recent shift towards including fire as a load case on structures, specifically internationally where many structures see their fire performance quantified and considered in design – the overarching goal of this CISC-ICCA research.

Examples of fire as a load can be seen in Annex K of the steel design standard CSA S16-14, as well as Appendix 4 of ANSI/AISC 360-10 that are both

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entitled *Structural Design for Fire Conditions*. Both of these material design standards now include provisions for the structural engineer to consider the effects of fire, albeit in an introductory manner. This can orient the engineer with performance-based fire engineering (as discussed in Advantage Steel issue 39, Fire Protection of Steel Structures).

The *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings* has also been previously referenced in Canadian case studies to help guide the process. Within CSA S16-14, a load case for fire is provided and contains the effects caused by the design basis fire as T_s. The design basis fire is discussed in the annex as being due to either a localized fire (non-flashover), or a post-flashover compartment fire. Most of the previously published Canadian case studies have focused on using Computational Fluid Dynamics (CFD) models, such as Fire Dynamics Simulator, to calculate temperatures in the structure for a given fire scenario.

While the results and the trends displayed can be insightful, this is not the only tool available and can be quite resource intensive if fire is to be considered as a load case in structural design. Indeed, there needs to be a range of tools available to the design depending on the complexity and boundaries of the problem. This is similar to what we see in the rest of structural engineering.

In many structural engineering practices, Building Information Modelling (BIM) is used by default on projects because of the benefits it brings. This technology is often leveraged to streamline the creation of structural analysis models. Fire Engineering, when fire is considered as a load case, can benefit from this same workflow integration and utilize the information already being captured in the BIM. As the case studies were developed as part of this CISC-ICCA research project, it is natural to develop links with BIM software to demonstrate synergy with the standard design processes being seen in practice.

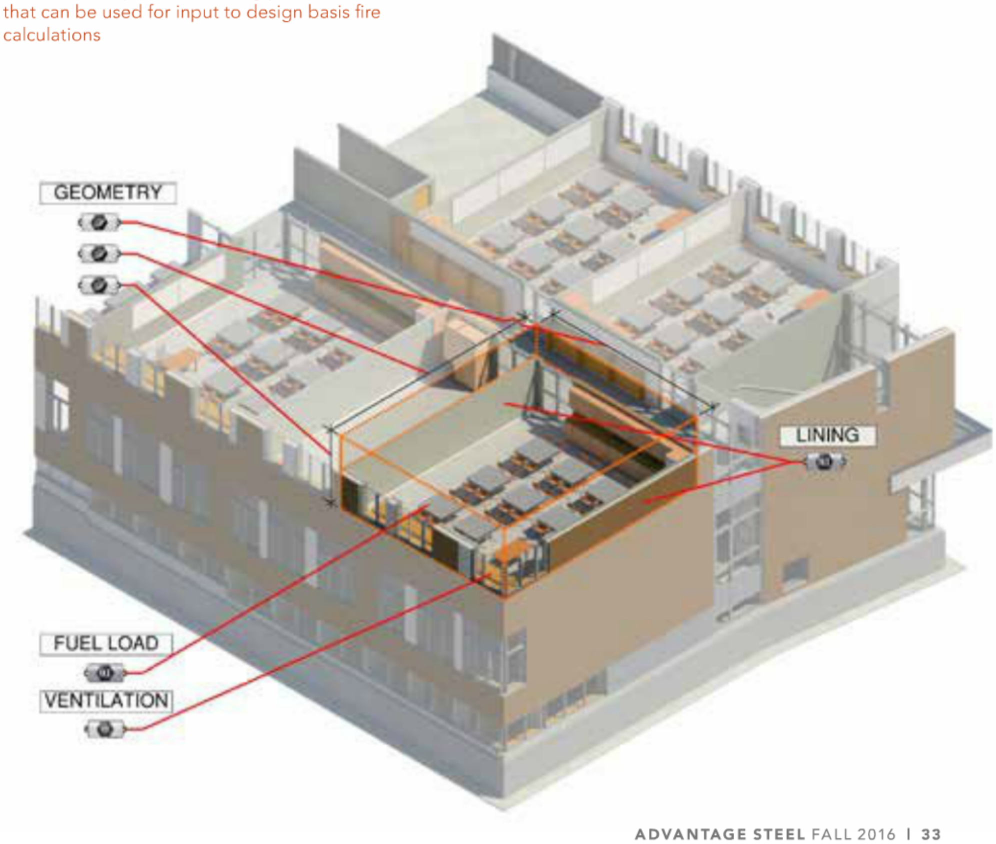
INTEGRATION WITH BIM

Industry best-practice uses BIM to increase coordination, efficiency, and document clarity. When used, these models are typically started at the very beginning of a project. These models contain both the structural and architectural information, among other disciplines, which means many of the parameters that can be used to define design basis fires are already being modelled (see Figure 1).

EUROCODE PARAMETRIC CURVES

A time-temperature curve that describes compartment fires and has often been used for design is the Eurocode Parametric Curve (CEN 1991-2002). That design fire is based off heat-balance calculations of average-sized compartments. The input to this equation includes the compartment geometry, interior finishes, ventilation conditions, and fuel load. A workflow can be developed that efficiently

FIGURE 1: Sample BIM showing parameters that can be used for input to design basis fire calculations



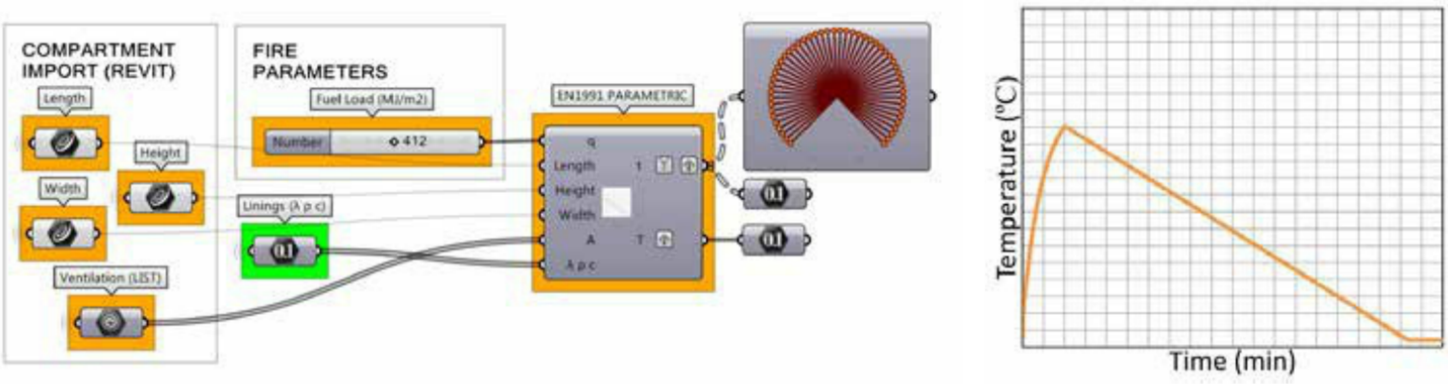


FIGURE 2: Simplified implementation of EN1991 Parametric Curve, using compartment geometry read from BIM and calculations subsequently performed in Grasshopper. Calculations are directly driven from BIM.

extracts this information directly from the BIM and calculates the temperatures resulting from a design basis fire for each compartment within a structure (Figure 2). The calculations can be performed by and optimized within Grasshopper by powerful optimization plug-ins such as Galapagos or Octupus. Grasshopper is a graphical programming interface seeing increased usage in structural design that allows for generative algorithms to drive the 3-D modelling capabilities of Rhinoceros. It allows for complex geometry to be parametrically modelled, optimization and form-finding exercises to be run, and direct two-way linkage with structural analysis software. It is an ideal tool to make complex steel structures a reality, from both an architectural and structural perspective.

Performing compartment fire calculations with direct input from the BIM allows for efficient analysis of the effects of temperature and can highlight areas that require special attention from the structural engineer – all without the complexities and resources that a CFD model could require. However, it has to be recognized that there will still be complex cases that exceed the limitations of the analytical correlations and could require a more robust CFD model.

TRAVELLING FIRES

In recent years, consideration has been given to fires which do not engulf the compartment homogeneously, and instead travel from one end to another. This behaviour is supported by observations of how accidental fires behave, as well as experimental observations.

It is a necessary consideration in design since contemporary buildings typically have large open spaces and other attributes that can fall outside the validity of the Eurocode Parametric Curve. An analytical method for determining the effects of a travelling fire have been well developed and documented by Rein et al (2007), Gales (2014), and Rackauskaite et al (2015). The method itself has been used for steel design in Europe, although it is often not the only design basis fire considered.

The travelling fire methodology is well suited to being integrated with BIM software since it is heavily dependent on the building geometry and properties. An example of a travelling fire moving through an open compartment is shown in Figure 3.

The benefit of powering the travelling fire calculations directly from BIM is that new geometry is automatically captured and actual

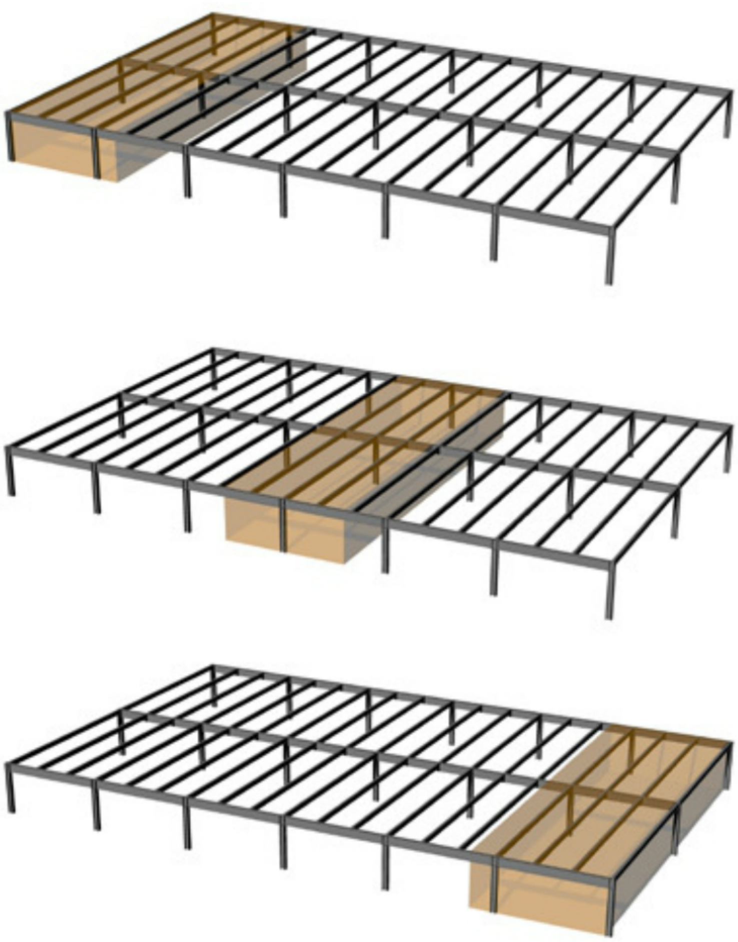
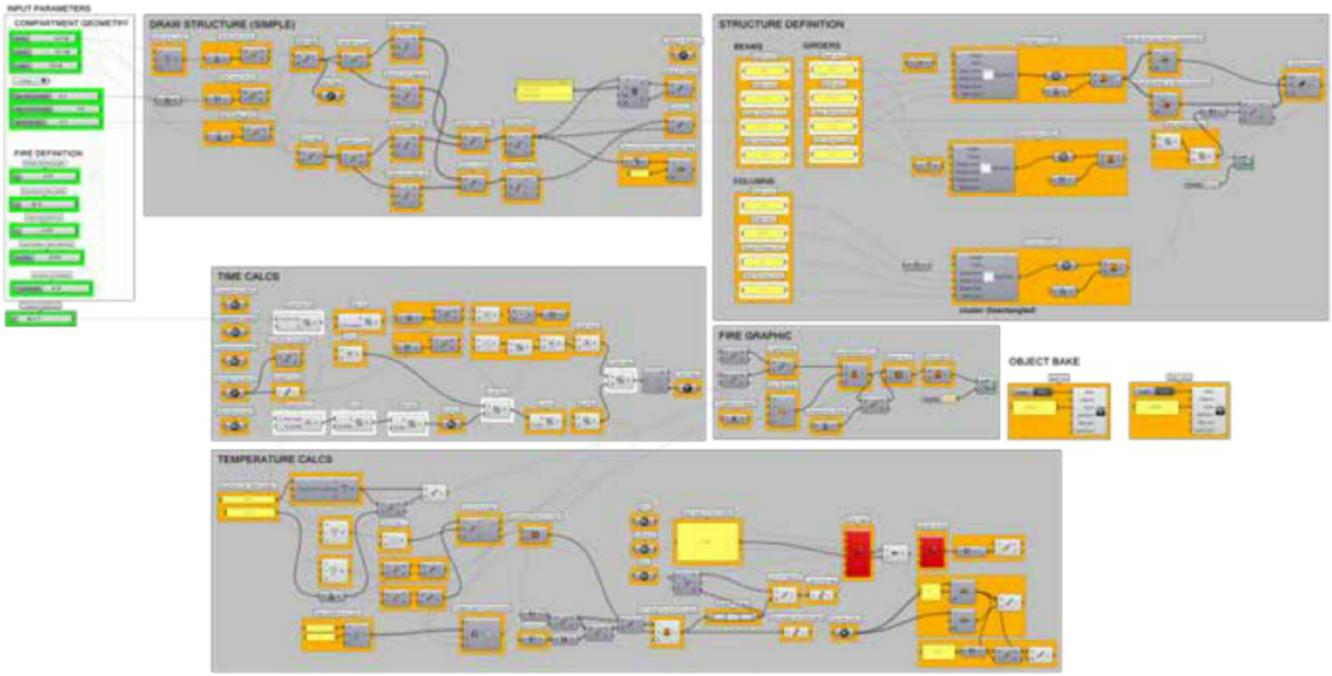


FIGURE 3: Visual representation of a travelling fire (equal to 20% of the floor area) within a sample structure



structural steel member sizes can be included in the heat transfer calculations. By utilizing Grasshopper to perform the calculations, there is also an opportunity to quickly assess ranges of parameters such as fire size, travel speed, flapping angle, etc. This proposed workflow is presented in Figure 4.

PRELIMINARY CONCLUSIONS

As fire begins to see consideration as a load case in structural design in Canada, there will have to be a range of tools considered that vary in complexity, scope, and limits of validity. Analytical correlations such as the Eurocode parametric curves and Travelling Fire Methodology represent opportunities to calculate expected structural temperatures for a range of fire scenarios which can inform a performance-based approach.

By using the BIM of a project to provide direct and real-time input with the fire calculations, similar to what we already see in structural design, efficiencies can be found and fire itself will see better inclusion as a load case in structural engineering in Canada and abroad. As fire engineering matures as a profession within Canada, it is expected that more links will be created with the structural engineering workflow so that the actual performance of our structures can be better quantified and accounted for in design.

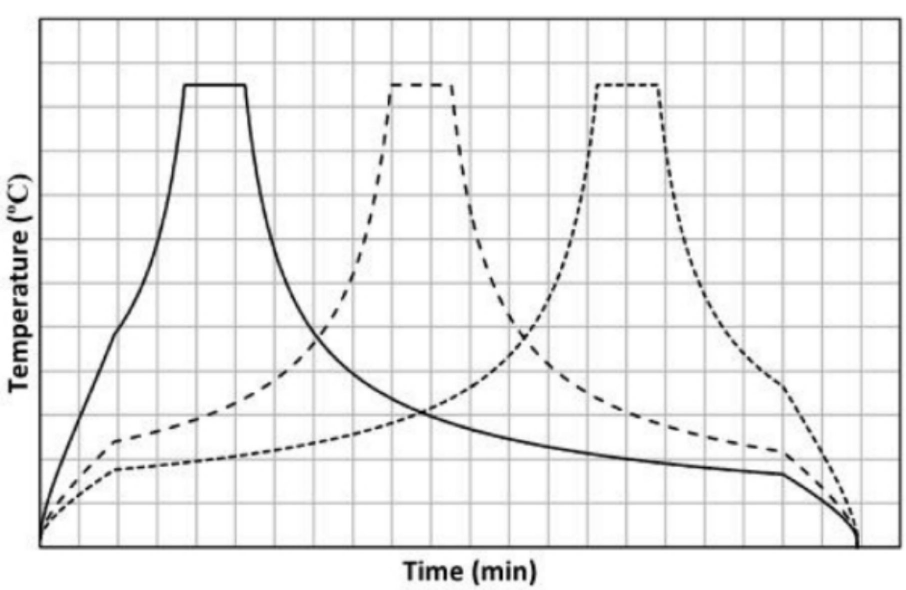


FIGURE 4: Sample workflow of BIM parameters imported to Grasshopper, with temperatures output for a range of design basis fires and locations of interest.

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Better defining how the performance-based fire protection opportunities can be integrated with the structural design is an essential part of this CISC-ICCA research project, and developing tools to define the design basis fires of real buildings will allow for demonstration case studies to show what benefits can be realized for Canadian practice. Ensuring these tools are validated, practical, and well integrated will make the performance-based process more appealing and transparent to all stakeholders. AS

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