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A USER INTERFACE TO COMPARE THE LIFETIME COSTS OF PRESCRIPTIVE AND PERFORMANCE-BASED FIRE DESIGNS OF COMPOSITE BUILDINGS

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ABSTRACT

The objective of this study is to develop a web-based interface tool to allow evaluating the economic impact of different structural fire designs for composite buildings. The economic assessment adopts a lifetime cost evaluation considering initial and maintenance construction costs, direct and indirect fire-induced losses, and co-benefits of the designs. A construction cost database with 130 prototypes of steel-framed composite buildings is built into the web interface to support the construction cost estimate. To estimate damage losses, fragility curves for composite floor systems are incorporated in the web interface based on probabilistic finite element simulations validated on full-scale fire tests. Variations in labor hours required for application of passive fire protection to steelwork and effects on construction time and rental revenues are estimated. Based on these cost components, the web interface generates the present value of the life-cycle cost for a cost-benefit comparison between alternative structural fire designs. A 16-story composite building is analyzed as a case study with comparison of the lifetime cost associated with prescriptive and performance-based designs. The methodology and its implementation in a user-friendly application can support assessment of the merits of performance-based structural fire designs for buildings.

Keywords: structural fire design; performance-based design; tensile membrane action; lifetime cost; cost-benefit analysis; web interface

1 INTRODUCTION

Statistics highlight the significant human and economic cost of fire, with more than a million building fires a year in the United States (U.S.) according to the National Fire Incident Reporting System (NFIRS). Structural fire design is an important layer of safety to mitigate fire risk. The cost of fire safety measures in building construction was estimated at 57 billion USD in 2014 in the U.S. [1], highlighting that changes in fire safety design methods can have considerable economic impact. For composite steel-concrete floor systems, fire protection materials are generally required for the steel members according to the building codes and specifications. However, research has shown that omitting fireproofing on selected steel members in composite slabs can result in the activation of tensile membrane action (TMA) under fire [2]. This TMA behavior can enhance the load-bearing capacity of the floors at large displacements, thereby achieving adequate fire integrity with reduced use of fire protection. This behavior was evidenced by several experimental fire tests [3]. As a result, performance-based structural fire design (PBSFD) has relied on TMA for the fire design of composite steel-concrete slabs with unprotected central beams in projects in multiple countries. As performance-based design (PBD) has become increasingly adopted by structural

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engineers, there is interest in assessing the economic impact of adopting PBD in lieu of a prescriptive approach for structural fire design.

Cost-benefit analysis (CBA) allows systematically evaluating and comparing design decisions in economic terms [4]. A recent study supported by the Fire Protection Research Foundation of the NFPA [5] conducted case studies on the economic impact of sprinkler systems, detection systems, and passive fire protection across various building types. Similarly, prior research has leveraged CBA to examine the cost effectiveness of different designs of elevators and exit stairs [6]. This approach can also be applied to estimate the economic impact of adopting a different structural design method instead of the prescriptive design. The American Society for Testing and Materials (ASTM) developed standards [7-11] to guide the CBA of investments in building design and building system decisions. These standards use various methods of evaluation, including the present value life-cycle cost analysis (PVLCC) [7], benefit-to-cost ratios (BCR) and savings-to-investment ratios (SIR) analysis [8], internal rate of return (IRR) and adjusted internal rate of return (AIRR) [10], and net present value (NPV) [11].

This paper focuses on the comparison of lifetime costs of prescriptive and performance-based fire designs for composite buildings. The approach adopts a PVLCC analysis implemented within a user-friendly web interface. This web-based tool allows integrating the cost components including the initial construction cost, lifetime maintenance cost, potential fire-induced lifetime damage loss, co-benefits, and environmental impact. Either user-provided or default parameters can be used. The interface includes a built-in construction cost database as well as estimates for the labor hours required for on-site work of applying passive fire protection to steel structures. This latter feature facilitates rent income analysis within the tool by accounting for variations in labor hours from different design. Besides, a set of fragility curves was developed to support the estimation of damage losses. By aggregating all cost components, the tool calculates the PVLCC, thereby enabling economic comparison between design choices. This provides stakeholders with an objective method for evaluating the economic impact of adopting PBSFD for buildings.

2 CONSTRUCTION COST DATABASE

The authors compiled a construction cost database that includes 130 building prototypes and eight building typologies consisting of four occupancy types [12]. The prototypes cover a range of occupancies and building sizes. The detailed costs for a prototype building are obtained from the RSMeans [13-16] database, an annually updated database of construction cost data that has been used in previous fire safety studies [6]. For each prototype, the cost of the substructure (e.g., foundations, basement walls), shell (e.g., floor system, roof, exterior windows), interiors (e.g., partitions, interior doors, stairs), services (e.g., elevators, sprinkler, electrical service), equipment (e.g., waste handling), and furnishings are obtained from the RSMeans square foot estimator. After collecting the cost details for the prototypes, some parameters are adjusted instead of using the default values for consistency in the type of steel-concrete composite systems considered. The default floor system is specified as a composite metal deck with shear connectors. The fire rating for the steel and composite structural members is adjusted based on the International Building Code (IBC) requirements.

The cost database includes cost breakdowns for the building fire safety measures. Results indicate that the total cost for fire safety measures in composite buildings ranges from 4% to 12% of the total construction cost of the building. The total cost for the sprayed fire-resistive material (SFRM) passive fire protection on the steelwork is between 0.00% and 1.23%. Additional insights, such as comparative costs of different fire protection materials, the effect of project location on construction costs, and more, are elaborated in [12].

3 LIFETIME COST ANALYSIS

The present value life-cycle cost (PVLCC) is used to evaluate the lifetime costs of prescriptive and performance-based fire designs of composite buildings. This approach aligns with the ASTM methods for economic assessments of building design investments [7, 9]. The PVLCC is estimated by Eq. (1):

$$PVLCC = C_I + C_M + D_D + D_{ID} - B \tag{1}$$

where C_I is the initial construction cost, C_M is the lifetime maintenance cost, D_D is the direct damage loss (including property and human loss directly caused by the fire), D_{ID} is the indirect damage loss, and B is the co-benefits. All future costs are converted to present value using a discount rate γ by Eq. (2).

$$P_0 = P_N \exp(\text{-}\gamma t) \tag{2}$$

When comparing the lifetime costs of prescriptive- and performance-based design, the cost difference can originate from all the cost components listed in Eq. (1).

3.1 Initial construction cost (C_I) and maintenance cost (C_M)

The construction cost database is used to support the development of a generalized method for estimating the cost of passive fire protection on steelwork in buildings. Figure 1 shows the detailed flowchart of three different approaches of assessing the construction cost of fire protection. The three approaches use the prototypes as baseline for calculating the fire protection costs but allow different levels of customization. The first method enables changing the fire design parameters of the building, such as omitting fire protection on some steel beams. The second method enables changing the building design, such as changing the story heigh and floor load. The third method estimates the fire protection cost based on user-defined steel component sizes and numbers. The construction cost database and the three described methods are incorporated in the web-based interface.

Figure 1 captures an on-site photograph showing a defective SFRM coating on the primary beam of a composite floor system. The defective fire protection may jeopardize the fire performance. This observation highlights the need for maintenance of passive fire protection systems to ensure their effectiveness during fire incidents. A common method for estimating maintenance costs is to consider them as a fixed percentage of the initial construction cost [5]. In this context, the lifetime maintenance cost C_M in the study period can be converted to present value by Eq. (3).

$$C_M = \frac{c_m}{\gamma}(1 - \exp(\text{-}\gamma t)) \tag{3}$$

where c_m is the annual maintenance cost, γ is the discount rate, and t is the number of years in the study period (further referred to as the “study year”).

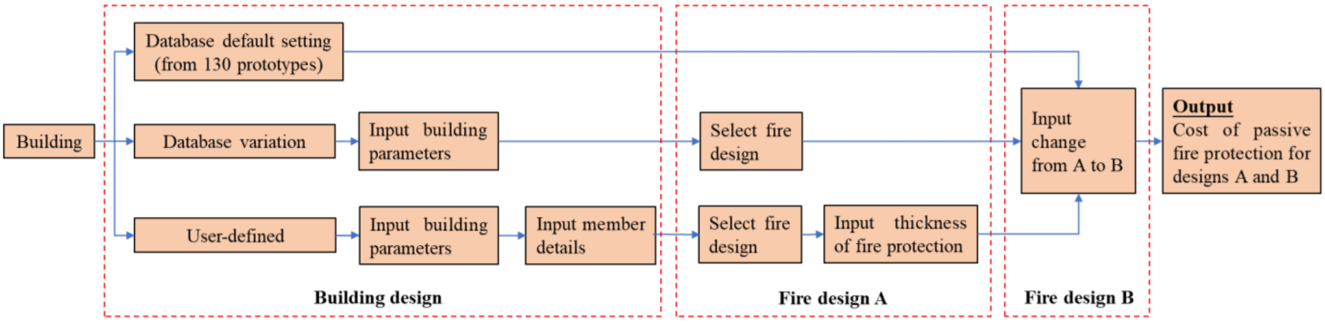


Figure 1 Flowchart of implemented methods for assessing the construction cost of fire protection in buildings.

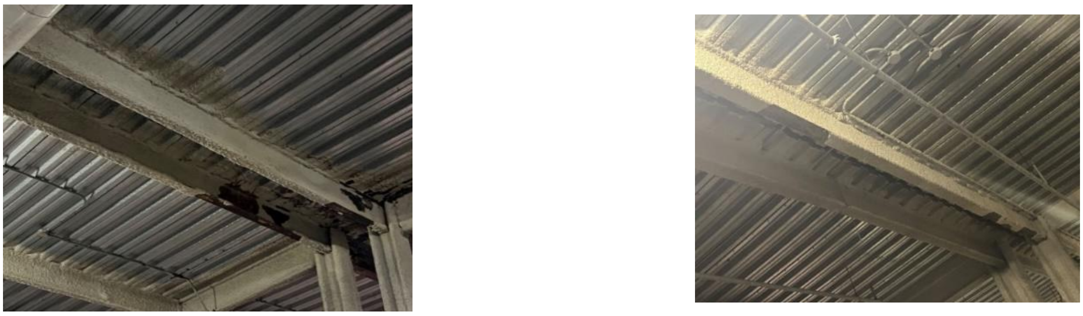


Figure 2 Illustration of defective SFRM on primary beam on the 1st floor of a high-rise residential building.

3.2 Direct losses ($\boldsymbol{D_D}$)

Direct damage losses are quantified using fragility curves. The curves relate the hazard intensity with the probability of reaching various damage states (DS). To generate the fragility points $P(DS = DS_i|q_m)$ for a specific DS_i under a given fire load q_m, advanced numerical analyses or on-site investigations are needed. The potential costs associated with each damage state are then inferred based on estimated repair costs, content losses, and potential human injuries associated with the respective damage state. For instance, if a composite slab reaches a major damage state, it is assumed that the entire floor system requires demolition and reconstruction [17], while under a minor damage state only the thermally damaged thickness of the slab needs repair. After establishing the costs associated with different damage states $C(DS = DS_i)$, a vulnerability curve $V(q)$ can be generated using Eq. (3). The vulnerability curve relates the hazard intensity with the probabilistic damage loss by combining the fragility curve with the damage costs for varying levels of damage [18].

$$V(q) = \sum_i^N P(DS = DS_i|q) \times C(DS = DS_i) \tag{4}$$

where N is the total number of damage states; $P(DS = DS_i|q)$ is the probability of the damage state i under fire load q; and $C(DS = DS_i)$ is the estimated cost under damage state i.

3.3 Indirect losses ($\boldsymbol{D_{ID}}$) and co-benefits ($\boldsymbol{B}$)

Indirect losses include losses resulting from the impact of the fire on building functionality and people's well-being, such as business interruptions, evacuations, relocations, and losses associated with irreplaceable assets. Considering that steel-concrete composite construction is commonly used in mid-rise and high-rise office or residential buildings, the costs related to relocations and business downtime can be considerable. These indirect losses would depend on the structural fire design since the latter influences the performance of the building structure in the fire, and thus also its functional recovery.

On the other hand, various types of co-benefits can arise from modifying a building fire design. Here, the method accounts for the differential on-site labor requirements for applying passive fire protection on steel structures, which can affect the construction timeline and, consequently, potential rental income. The co-benefits can be considered as the reduction in rent loss due to the reduction in required labor hours. Labor hours associated with fire protection are obtained from unit labor cost of fire protection material and the corresponding labor daily cost. For example, crew G-2 as listed in [16] is used when considering the cost of applying the SFRM and its daily cost is about \$1140, and then the unit labor hour needed (i.e., the time needed for applying the fire protection on-site) is computed by dividing the unit fire protection labor cost by the labor daily cost.

The environmental impact of various building designs can also be incorporated into the co-benefits. For instance, adopting a PBSFD that leaves the central beam unprotected could result in a reduced global warming potential (GWP) for the building due to the lower amount of fire protection. A design with superior fire performance also offers reduction in GWP due to a reduced likelihood of requiring repair or reconstruction post fire. Which of these effects dominates will depend on the specifics of the case. The holistic comparison of PBSFD and prescriptive design can therefore consider not only safety and resilience but also carbon footprint resulting from construction material usage and repair works.

4 IMPLEMENTATION IN A WEB INTERFACE

The construction cost database introduced in Section 2 and the lifetime cost analysis method introduced in Section 3 have been integrated into a web-based interface. The interface provides a stepwise procedure to conduct comparative lifetime cost analysis on different fire design methods, see Figure 3. Pre-defined unit costs, analysis methods, and parameters can be used for both the building and fire designs. User-defined values can be used instead of the default settings for conducting analysis of customized designs or projects.

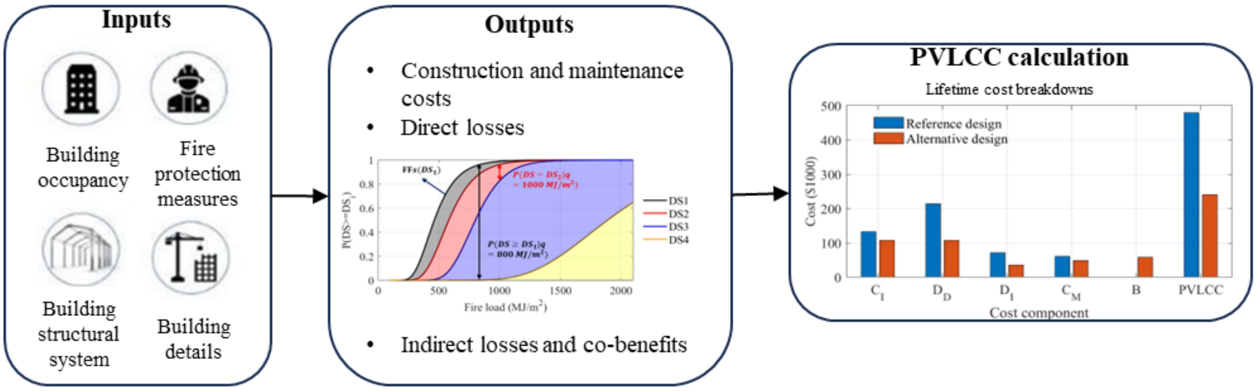


Figure 3 Web-based user interface to conduct the cost-benefit analysis of different designs.

Here, the web interface is introduced along with a case study with two fire design methods. The case study considers a 16-story building with 10 ft. story height and total floor area of 233,063 sq. ft. Two fire design methods are considered, as listed in Table 1. Design 1 is based on the prescriptive method with all the central beams protected. Design 2 includes fire protection on half of the beams only, to represent a PBD with unprotected central beams and extra slab reinforcement to rely on tensile membrane action (TMA).

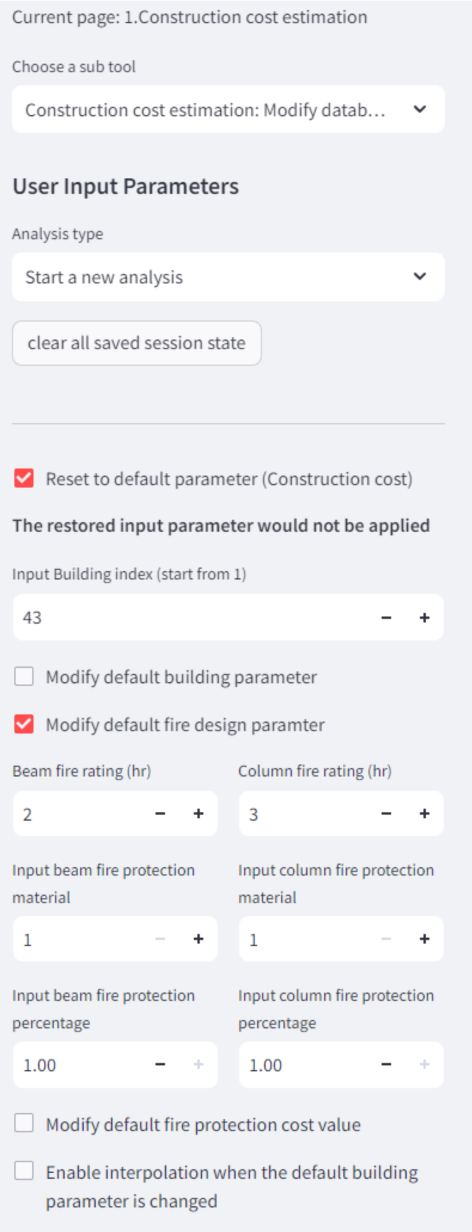
Table 1 Fire protection parameters of the five different scenarios.

Design No.	Fire protection material	Percentage of protected Beams	Slab reinforcement cost
1 (Prescriptive)	SFRM	100 %	100%
2 (PBD)	SFRM	50 %	150%

4.1 Step-1 Construction and maintenance cost

When the tab of construction cost estimation within the web interface is activated, users are prompted to select a cost estimation method. It can be either modifying the existing building prototypes in the building database or inputting a user-defined building. In the case study, an existing building in the database is selected, with parameters shown in Figure 4 (a). The building index refers to the construction cost database which is accessible from the interface. The interface enables modifying both the building design parameters (e.g., story height, floor loads, typical bay size, etc.) and the fire design parameters (e.g., beam and column fire rating, fire protection material, and percentage of protected beams and columns). Besides, the interface allows users to replace the default material unit cost value with their own market-specific data to enhance the estimation accuracy. For the reference design (prescriptive) in this case study, default fire design parameters are set from IBC. For the alternative design, the percentage of protected beam is adjusted from 100% to 50%, illustrating a scenario with unprotected central beams, and the parameters for alternative design are shown in Figure 4 (b).

Once the necessary parameters have been input, the web tool can estimate the construction cost along with the required labor hours for applying passive fire protection, as shown in Figure 4 (c). In this case study, the unit cost of fire protection is based on RSMeans 2022 national average value. The unit material cost typically includes both the bare material cost and the installation cost.



Current page: 1.Construction cost estimation

Choose a sub tool: Construction cost estimation: Modify datab…

User Input Parameters

Analysis type: Start a new analysis

☑ Reset to default parameter (Construction cost)

The restored input parameter would not be applied

Input Building index (start from 1): 43

☐ Modify default building parameter

☑ Modify default fire design paramter

Beam fire rating (hr): 2

Column fire rating (hr): 3

Input beam fire protection material: 1

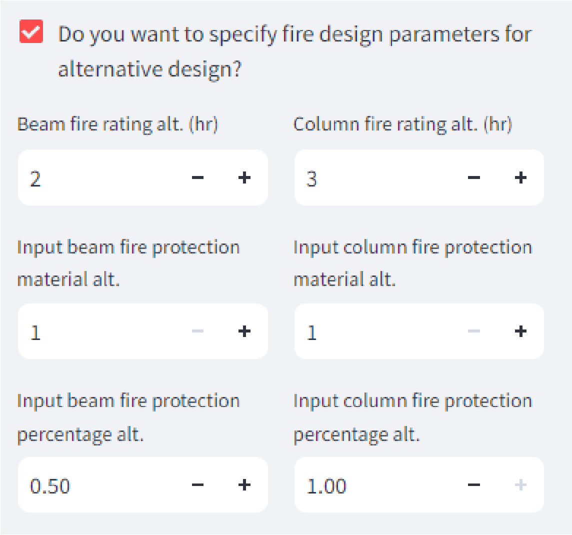
Input column fire protection material: 1

Input beam fire protection percentage: 1.00

Input column fire protection percentage: 1.00

☐ Modify default fire protection cost value

☐ Enable interpolation when the default building parameter is changed



☑ Do you want to specify fire design parameters for alternative design?

Beam fire rating alt. (hr): 2

Column fire rating alt. (hr): 3

Input beam fire protection material alt.: 1

Input column fire protection material alt.: 1

Input beam fire protection percentage alt.: 0.50

Input column fire protection percentage alt.: 1.00

(b) Fire design parameter input window for alternative design.

Updated cost data with user-defined cost value

	Floor	Column	Partition	Sprink
Cost ($)	184,119	132,165	0	
Cost multiplier	0.0067	0.0048	0	
Labor hour	1,581	1,135	0	

Alternative design

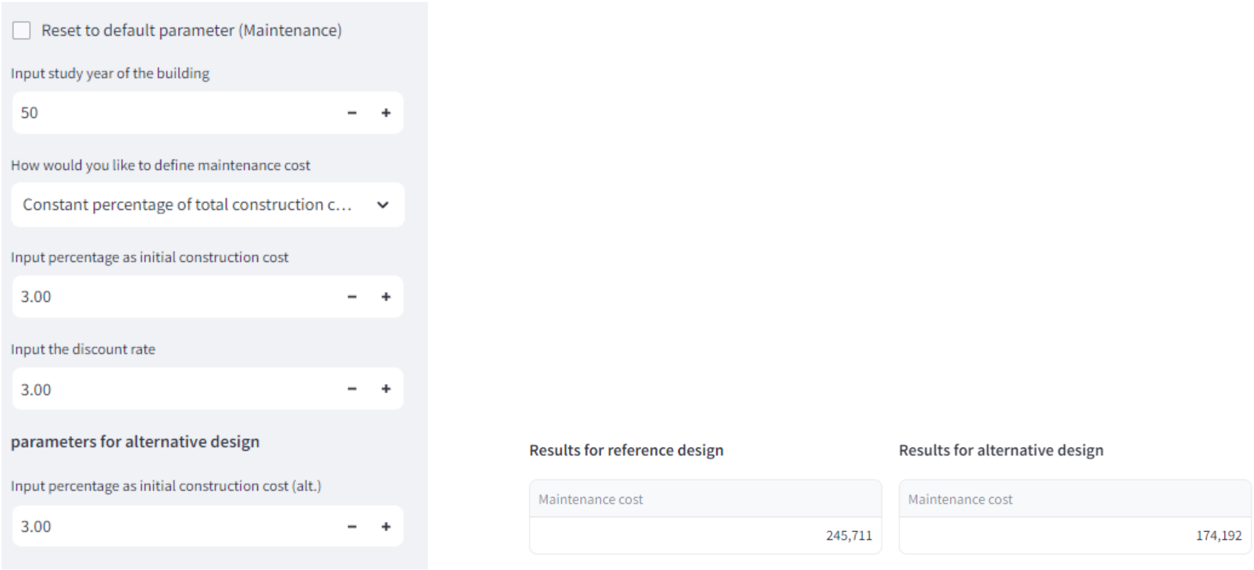
	Floor	Column	Partition	Sprin
Cost ($)	92,059	132,165	0	
Cost multiplier	0.0033	0.0048	0	
Labor hour	790	1,135	0	

(a) Design parameter input window for reference design.

(c) Construction cost of passive fire protection on the steelwork for the two design methods.

Figure 4 Sample of the construction cost estimation

To estimate the lifetime maintenance cost using the default method, users must input specific parameters such as the study year, the discount rate, and the annual maintenance cost as a percentage of the initial construction cost. The parameter input menu is shown in Figure 5 (a). This process allows for the customization of maintenance rates for alternative design methods, accommodating differences in fire protection materials. The tool then computes and displays the lifetime maintenance cost, as shown in Figure 5 (b).



☐ Reset to default parameter (Maintenance)

Input study year of the building: 50

How would you like to define maintenance cost: Constant percentage of total construction c...

Input percentage as initial construction cost: 3.00

Input the discount rate: 3.00

parameters for alternative design

Input percentage as initial construction cost (alt.): 3.00

Results for reference design

Maintenance cost: 245,711

Results for alternative design

Maintenance cost: 174,192

(a) Maintenance parameter input window.

(b) Maintenance cost of passive fire protection for the two design methods.

Figure 5 Sample of the maintenance cost estimation

4.2 Step-2 Direct losses

Within the web interface, users have access to nine predefined fire fragility curves. The curves were developed based on numerical FE models that were calibrated against the full-scale fire tests on composite structures conducted by the NIST. These curves account for various design parameters of composite floor systems. Fragility curves 1-3 correspond to the prototypes that were tested at the NIST, while fragility curves 4-9 capture variations in parameters such as slab rebar areas, boundary conditions, and aspect ratios based on the NIST prototypes. To accommodate a wider range of scenarios and user needs, the interface also offers the capability to upload custom, user-defined fragility curves. In the case study, fragility curves one (based on NIST test #1 with protected central beam) and three (based on NIST test #3 with unprotected central beam and enhanced slab rebar) are chosen for Design 1 and Design 2, respectively.

Fire frequency in the case study is evaluated from the NFIRS fire event database (years 2012-2022) and the U.S. Census Bureau data on building stock. As composite floor systems are widely used in mid-rise and high-rise buildings, data in NFIRS is taken for buildings taller than four stories. The average building stock is determined using information from the U.S. Census Bureau for the years 2011 and 2021. Consequently, the frequency of structural significant fire, defined as fires with flame spreading beyond the origin, in multi-family dwellings is estimated as $2.97 \times 10^{-7}/sq.ft.$

The direct losses associated with damage states DS1 to DS3 are evaluated based on data in [17, 19]. These losses are mostly linked to repair needs within the affected compartment after the fire.

Damage state DS4, indicative of a structural integrity failure, encompasses a broader range of potential outcomes and is thus more challenging to quantify. A sensitivity analysis is conducted to explore the variations in direct damage losses associated with different assumed values for DS4 loss. The "g-value" is introduced as a metric, representing the loss at DS4 normalized by the initial construction cost of the floor system within the fire compartment. This g-value can take very large values if the integrity failure results in fire spread in multiple compartments and/or complete structural damage, since it is compared to the cost of the floor in a single compartment only (to make the analysis independent of the number of compartments in the building).

Figure 6 plots the relationship between the g-value and the ratio between the direct loss D_d respectively for the PBD and prescriptive design. A ratio below one means that the floor designed with the PBD approach (Test #3) has lower expected direct loss from fire compared to the one designed with the prescriptive method (Test #1). Higher g-values give more weight to integrity failure. It can be seen that the PBD becomes increasingly superior to the prescriptive design as the g-value increases. This is because the PBD has a much lower probability of integrity failure than the prescriptive design, as the addition of steel reinforcement in the slab leads to a robust fire behavior. Since the estimated direct loss is conditioned to the fire load distributions (through the fragility functions), results are plotted for different building occupancies, themselves associated with different fire load statistics. The PBD leads to lower expected direct losses compared to prescriptive method for buildings with relatively large average fire load (e.g., dwelling, library) as long as the g-value larger than 3. However, since the activation of TMA relies on large deflections, the PBD tends to have higher direct losses for lower average fire load (e.g., school, hotel, theatre) until a large g-value (300 to 10,000) is applied. The results thus suggest that the most favorable design, in terms of direct fire losses, depends on the type of occupancy (because it influences the fire load) and the consequences of integrity failure (quantified through the g-value).

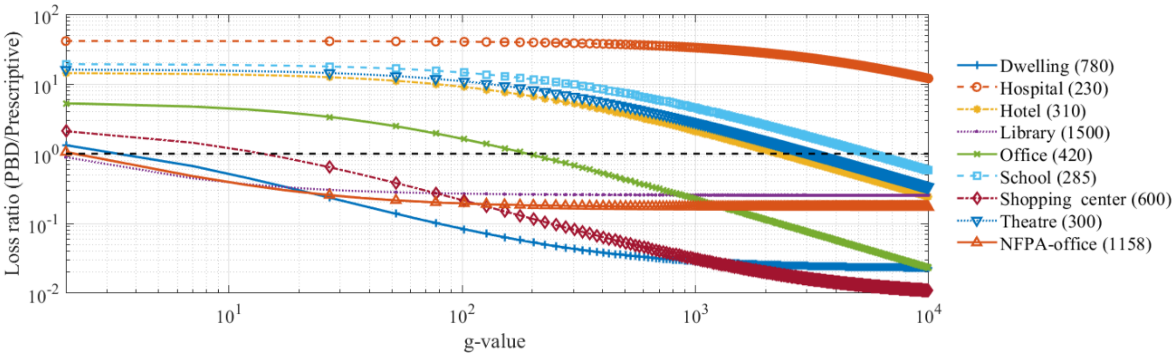


Figure 6 Ratio of direct damage loss for the two design approaches, considering different occupancies, as a function of the direct loss at DS4 quantified through g-value. (Mean values of the fire load are listed in brackets).

In this case study, the g-value is selected as 100 for illustration purposes. The selected fire load is based on residential buildings, which follows the Gumbel type 1 distribution with a mean value of 780MJ/m^2 and a standard deviation of 234MJ/m^2. Figure 7 (a) details all the input values utilized for the direct damage analysis within this case study, while Figure 7 (b) displays the resulting outputs. The results section provides the average loss per severe fire incident, the expected annual loss, the applied fragility curves, the distribution of the fire load, the distribution of damage losses, and the corresponding vulnerability curves. The outcomes indicate that Design 2 (PBD), tends to incur significantly lower fire losses per severe incident compared to Design 1 (Prescriptive). This observation aligns with the conclusions drawn from Figure 6, further substantiating the potential advantages of PBD in reducing fire-related direct losses.

Current page: 3.Direct damage estimation

User Input Parameter

☐ Reset to default parameter (Direct damage)

Input probability of severe fire in a compartment (*10-7): 25.60

Input number of compartment: 234

How would you like to define the fragility curves: Use built-in fragility curves

Input the index of the built-in fragility curves: 1

Enter your damage state value (comma-separated):
4932.393846153846,
18701.993333333336,
34115.724102564105,
2055164.1025641026

Input damage state cost value:

value
4,932.3938
18,701.9933
34,115.7241
2,055,164.1026

How would you like to define the fire load distribution: Use given distribution (gumbel distribution)

Input mean value: 780

Input standard deviation: 234

parameters for alternative design

Input the index of the built-in fragility curves (alt.): 3

Enter your damage state value (comma-separated) alt.:
4837.973333333333,
18343.982222222225,
33462.648888888885,
2015822.222222222

Input damage state cost value for alt.:

Results for reference design

Average loss per severe fire	Annual loss	Study year
583,243	3,493	50

Results for alternative design

Average loss per severe fire	Annual loss	Study year
47,993	287	50

(a) Direct damage parameter input window.

(b) Direct damage for the two design methods.

Figure 7 Sample of the direct damage estimation

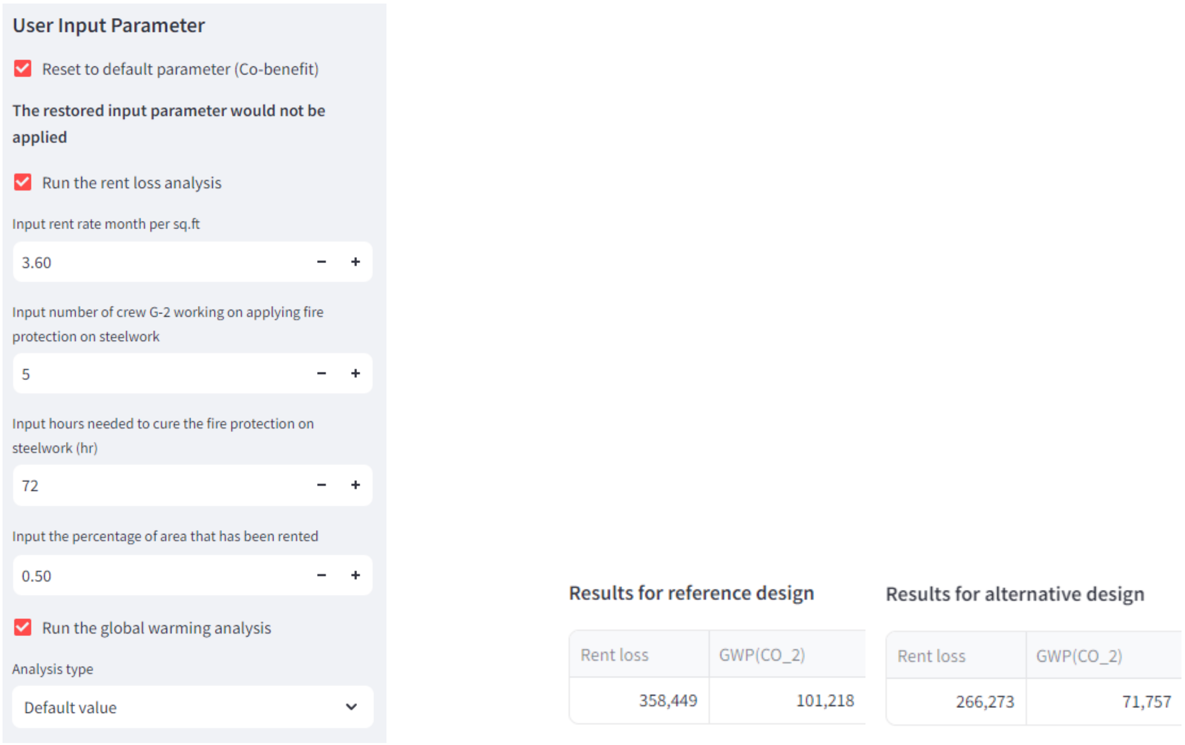
4.3 Step-3 Indirect losses and co-benefits

The current version of the web tool does not provide a default method to estimate the indirect losses, but it offers users the capability to input their own estimates of indirect losses to facilitate further lifetime cost analysis.

For the co-benefit analysis, the built-in functions enable analysis of the variation in the rent income due to the changes in the construction schedule. It is important to note that the unit labor costs have been integrated into the overall construction material costs. Therefore, the analysis of labor hour primarily focuses on how reductions in labor hours might influence the construction schedule and, by extension, rental income.

The construction schedule can be significantly affected by the number of crews involved in applying the fire protection materials, with the default setting in the tool being two crews. This parameter can be adjusted to reflect different operational realities. The default rent rate is 3.6 USD per sq. ft per month (the average office rent rate is 5.0 USD in NYC). Users also have the option to specify what percentage of the area is considered when calculating rental income, with the default value set at 50%. This flexibility allows users to tailor the analysis to their specific project conditions and market environments.

The GWP associated with passive fire protection materials is estimated within the web tool based on data from the product's Environmental Product Declaration (EPD) reports. The default setting in the web interface assumes that two units of weight for SFRM result in the generation of one unit of CO_2 weight. This automatic estimation facilitates a preliminary assessment of the environmental impact during the construction phase. In the future, the module of lifetime GWP analysis will be added. This addition aims to provide a more comprehensive evaluation of the potential environmental impacts attributable to various damage states and building designs, contributing to more sustainable construction practices.



User Input Parameter

☑ Reset to default parameter (Co-benefit)

The restored input parameter would not be applied

☑ Run the rent loss analysis

Input rent rate month per sq.ft: 3.60

Input number of crew G-2 working on applying fire protection on steelwork: 5

Input hours needed to cure the fire protection on steelwork (hr): 72

Input the percentage of area that has been rented: 0.50

☑ Run the global warming analysis

Analysis type: Default value

Results for reference design

Rent loss	GWP(CO_2)
358,449	101,218

Results for alternative design

Rent loss	GWP(CO_2)
266,273	71,757

(a) Co-benefit parameters input window.

(b) Co-benefit for the two design methods.

Figure 8 Sample of the co-benefit estimation

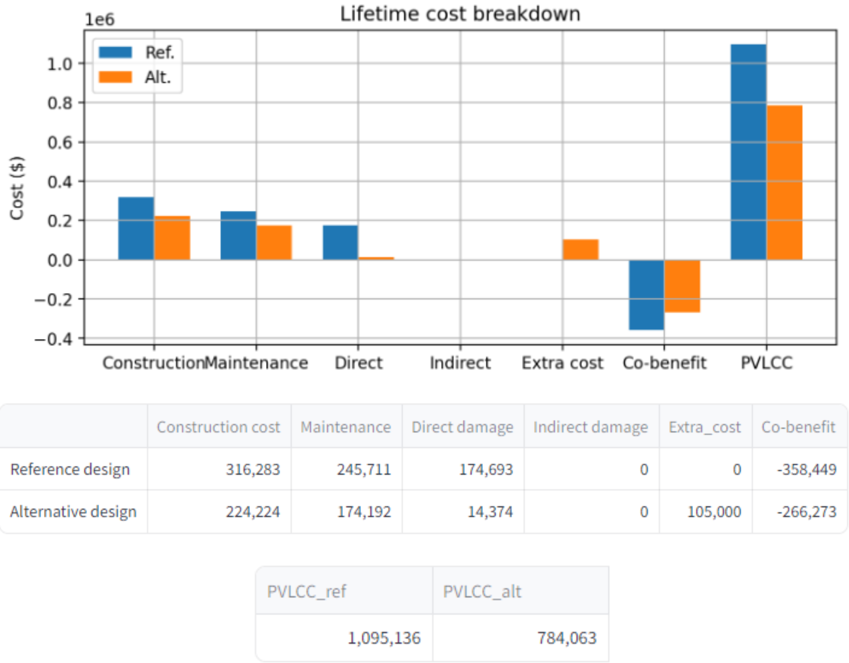
4.4 Step-4 Additional cost components

Section 4.1 to Section 4.3 detail the computation of cost components including construction, maintenance, direct damage, indirect losses and co-benefits. However, it is recognized that alternative design choices might incur additional costs under certain circumstances. For example, it is established [20] that the development of tensile membrane action highly relies on the amount of reinforcement in the concrete slab. Therefore, the web tool offers users the capability to input custom values for any extra costs associated with alternative designs. In the case study, an additional investment of 105,000 USD is applied to Design 2 to account for the increased amount of steel reinforcement. According to the cost data of welded-wire mesh in RSMeans, increasing the welded mesh density from 60 mm^2/m to 289 mm^2/m entails a 55% additional cost, with 85% of this increase stemming from the material costs alone. Consequently, in the case study, the impact of altering the welded-wire mesh on the construction timeline is considered negligible.

5 RESULTS OF THE PVLCC CALCULATION

Once introducing all the cost components through the different steps is completed, the interface can automatically calculate and plot the breakdown lifetime costs and the PVLCC. These costs are provided side-by-side for both the reference design and one alternative design. This allows comparing, for a given building, two structural fire design approaches, for example based on prescriptive and PBD methods.

The results for the case study are shown in Figure 9. Design 2 (i.e., the PBSFD) has a significantly lower PVLCC in comparison to Design 1. This reduction is attributable to the savings in the construction cost, maintenance cost, damage losses and rent losses, which offset the additional expenditure on slab reinforcement in Design 2. It is important to emphasize that the results only refer to this specific case study with its specific design parameters, such as the mean fire load of 780 MJ/m^2, the fragility curves based on the NIST prototypes, etc. In the future, a range of situations will be studied with the tool to draw general conclusions for a range of buildings and design parameters.



	Construction cost	Maintenance	Direct damage	Indirect damage	Extra_cost	Co-benefit
Reference design	316,283	245,711	174,693	0	0	-358,449
Alternative design	224,224	174,192	14,374	0	105,000	-266,273

PVLCC_ref	PVLCC_alt
1,095,136	784,063

Figure 9 Sample of the outputs of the life-cycle cost estimation for a composite building designed either with a prescriptive (Ref.) or a performance-based approach (Alt.).

6 CONCLUSION

Comparing the economic impact of different designs requires a holistic approach that incorporates not only upfront investment costs in fire protection measures but also estimates of lifetime costs associated with the expected fire performance. Evaluation of these different cost components relies on the combination of data and simulation results from probabilistic fire analysis. To streamline these evaluations and the economic impact assessment, we provided a stepwise procedure in a web interactive environment. The web interface provides data and a method to compare the lifetime costs of different fire design methods, which can support decisions by designers as well as evolution of building codes and standards.

The web interface provides an approach for evaluating different structural fire designs of composite buildings. It encompasses a cost database derived from the analysis of 130 prototypes, as well as fire fragility functions derived from FE analyses. It also allows user-defined adjustments to building and fire design parameters and the integration of user-defined data. The web interface is built to evolve with further data, for example to incorporate environmental impact assessments through the global warming potential (GWP) of fire protection materials. This will enable conducting economic evaluations with sustainable building practices, thereby supporting the construction industry's shift towards more environmentally responsible and cost-effective structural fire design methods.

A case study was conducted through the stepwise procedure in the web interface. The study compared the lifetime costs of a building designed according to prescriptive and PBD methods. The results indicate that the PBD design has an associated cost that is significantly lower than the prescriptive design, despite a required additional upfront investment in steel reinforcement in the slab. The PBD offers savings in fire protection construction cost, maintenance cost, expected damage losses in case of fire, and rent loss which more than compensates for the extra cost in the slab reinforcement. This case study is based on specific inputs and should not be generalized before additional studies have been conducted, for example on building occupancies with lower average fire load.

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