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A Multi-Performance Comparison of Long-Span Structural Systems

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A multi-performance comparison of long-span structural systems

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[1] Long span program requirements often determine the structural system
[2] Structural systems impact a building's overall embodied energy, operational energy, longevity and reuse potential
[3] Significant resources are required to extract, process, transport and assemble building components
[4] Integrated design can significantly reduce the operational energy and the initial materials required for new construction
[5] Multi-performance structural systems can improve new and existing buildings while potentially lowering construction costs

ABSTRACT: When a building requires a long span, especially on the ground floor of a multi-story building, the long span often determines the structural system used early in the design pro-cess without any other consideration. Commercial and residential buildings are responsible for roughly 40% of all carbon emissions and energy use, more than any other sector in the USA. Moreover, this excludes the significant energy and emissions required to extract, process, trans-port and assemble building components. Globally, the production of cement alone accounts for 4% of carbon dioxide emissions. Consequently, reducing the environmental impact of building construction and operations is critical to address interrelated issues such as global climate change. The role of structural systems in the overall performance of a building has been largely neglected. Very little consideration is given to other ways the structure could contribute to improving sustainable outcomes. This is in spite of the fact that the structure of a typical office building contributes roughly one-quarter of the total embodied energy and is, at the very least, the armature for all other building systems. Existing research into the embodied energy of structural systems focuses on hypothetical office buildings with uniform structural layouts, a range of comparable, existing office buildings or housing without comparing or accounting for the long spans. Like all other aspects of a building, the structural system needs to be understood in terms of wide range of sustainability issues: embodied energy, operational energy, longevity and re-use. If structural systems could be left exposed without additional finishes as well as be configured to provide a higher level of thermal comfort, more daylight and acoustic isolation, this could significantly reduce the operational energy and the initial materials required for new construction. These multi-performance structural systems, in contrast to high-performance structural materials that aim to only improve structural properties, offer considerable and largely untapped opportunities to improve new and existing buildings while potentially lowering construction costs. Using a five-story, 2,500 square-meter (27,000 square-foot) classroom building with 24.4 meters by 30.5 meters (80 feet by 100 feet) auditorium on the ground floor as a case study currently in design at Oregon State University, the multi-performance criteria for four long span systems, including steel, two concrete and wood, are compared (Figure 1). These criteria include embodied energy and carbon, structural and spatial properties, acoustic properties, fire protection and thermal properties. (Tables 1, 2 and 3).

This paper argues that the most efficient structural solution may not be the best in terms of overall sustainability outcomes, and the selection of a structural system should be based on multi-performance criteria. The objectives of this research is to inform integrated design teams during schematic design phases and project development processes to be more mindful of the performance of structural systems in terms of other aspects, including thermal, acoustic, environmental, and fire resistance, versus simply acting as the structure alone. One important criteria to add to this study would be the cost not just of the structural materials, but the cost for each system to meet certain acoustic, fire-rating and thermal criteria and the additional materials it would entail.

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CASE STUDY: Using a 5-story, 27,000 square-foot classroom building with 80 foot by 100 foot auditorium on the ground floor as a case study currently in design at Oregon State University, the multi-performance criteria for four long span systems, including two type of concrete, steel and wood, are compared in terms of embodied energy and carbon, structural and spatial properties, acoustic properties, fire protection and thermal properties.

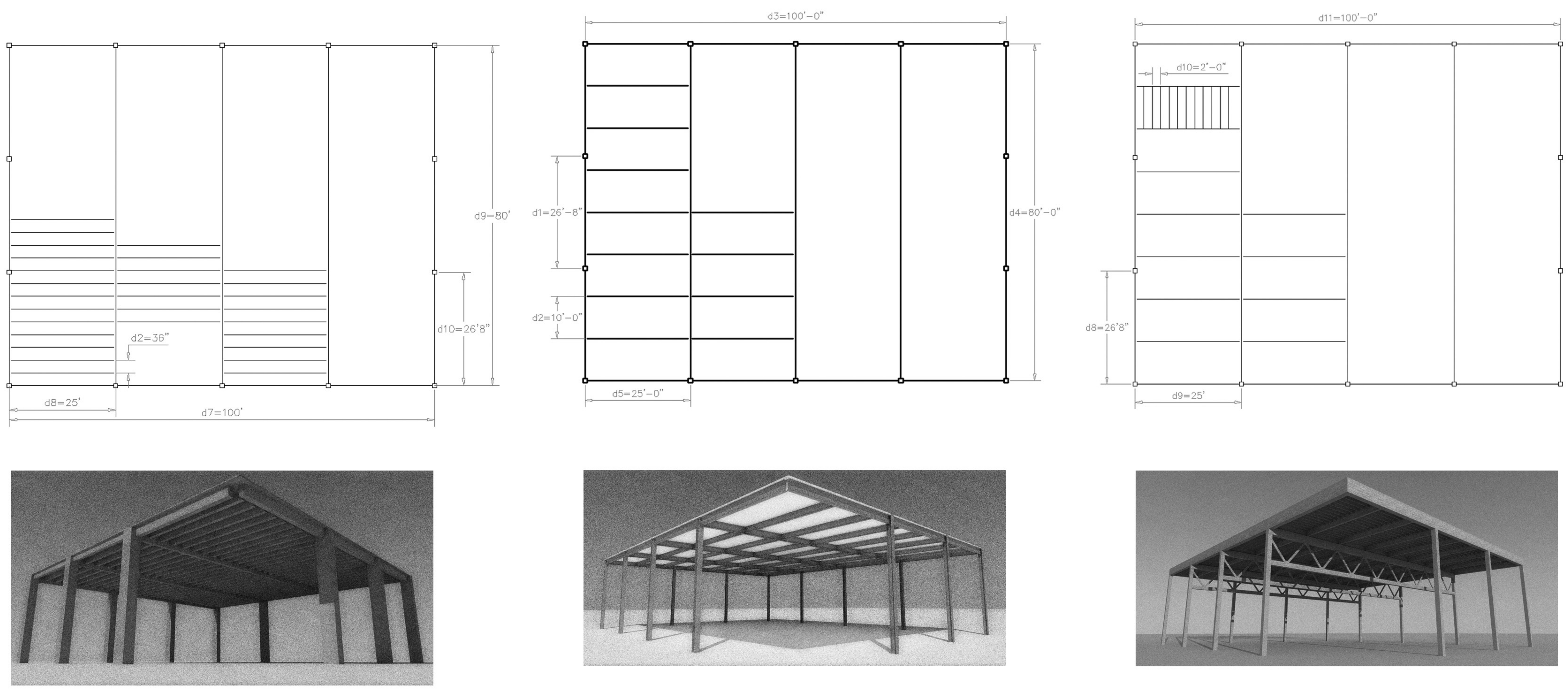

Figure 1. Three long span floor systems considered in this study (left to right): concrete joists and post-tensioned concrete beams, steel wide-flange beams and girders, wood joists, glue-laminated beams and trusses. A fourth long span, post-tensioned concrete slab and beams, is not shown but is identical to the layout of the other concrete system without the joists.

Table 1. Embodied energy and embodied carbon of long span systems.

Structural System	Embodied Energy (TJ)		Embodied Carbon (1,000 kg CO2)	
	Virgin	Non-Virgin*	Virgin	Non-Virgin*
PT Concrete Slab	0.77	0.54	99	73
Concrete Joist	0.60	0.40	74	47
Steel Wide-Flange	2.62	0.98	229	65
Wood Truss	0.35	n/a	21	n/a

*Non-virgin materials include 20% portland cement replacement with fly ash for concrete and 93% recycled content for all structural steel.

Table 2. Multi-performance characteristics of long span systems.

Structural System	Weight (kg/m^2)	Depth (m)	STC	ICC	Fire-rating	IBC Cat.
PT Concrete Slab	579	1.57	55	30	3 hr	I, II, III, V
Concrete Joist	447	1.63	50	30	3 hr	I, II, III, V
Steel Wide-Flange	385	1.17	51*	21*	0 hr*	I, II, III, V
Wood Truss	72	3.05	38**	32**	1 hr**	V, VI

*These values assume no additional fire protection or materials beyond what is required for the structure, however there are several strategies, all requiring additional materials, for increasing both the acoustic performance and fire-rating of the steel structures.
**These values assume a 5/8-inch sheet of fire-rated gypsum board is attached to the bottom of the sub-purlins and could be increased with the use of additional materials.

Table 3. Thermal multi-performance characteristics of long span systems.

Structural System	Mass (MJ*K^{-1})	Conductivity (W*m^{-1}*K^{-1})	Resistance (m^2*K*W^{-1})*
PT Concrete Slab	358	1.13	0.112
Concrete Joist	276	1.13	0.042
Steel Wide-Flange	216	45.0	0.056
Wood Truss	92	0.14	0.44

*Multiply by 5.75 to get ft^2-°F-hr/Btu.