EXPERT VALIDATION OF TALL-D: A KBS FOR TALL BUILDINGS DESIGN

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Abstract

A brief overview of validation of the Tall-D knowledge-based system is presented. The objective of the validation process was to have industry experts participate and to compare the tall building design alternatives generated by Tall-D to those designed in actual projects. Two experts compared test-cases with the designs produced by Tall-D system. These design sessions also enabled the experts to critique the individual cases as well as the overall performance of Tall-D. The overall performance was evaluated through a comprehensive questionnaire on the different features of Tall-D as an automated design tool. The multi-storey test-cases used are actual buildings: Place du Canada, IBM-Marathon and 1000 de La Gauchetière, all located in Montreal. One of the test-cases and the results of the questionnaire-based validation of Tall-D are presented.

Keywords: integrated design system, validation, multi-storey office building, preliminary design, architecture, structure.

1 Introduction

Tall-D is a knowledge-based system for the preliminary design of tall buildings. Tall-D system can generate alternative building configurations and corresponding preliminary structural designs. In the absence of computer-based tools and also due to resource and time constraints, the current preliminary design tasks are mostly restricted to exploring one or two design alternatives, often proceeding with a less than efficient solution. Therefore a computer-based design tool that can be used by designers at the initial stages of a project to explore many design alternatives on a comparative basis will, lead to better and more economical designs than those produced without such a design tool. Following is a discussion of the validation and verification process as applied to the Tall-D system.

2 Software validation and verification

Validation and verification (V & V) of software are two terms that are generally differentiated from one another. Validation is considered a check on software performance based on output, i.e. performance-oriented. In contrast, verification is a check for conformance to system specifications established at the design stage, i.e. implementation-oriented. The former is a functionality check and the latter, a "structural" check. Validation and verification of knowledge-based systems represents an active research area (Chander 1996, Gupta 1993). In the early days of knowledge-based systems, validation and verification was done on an ad hoc basis. Then, formal methods and tools were developed to check knowledge-bases (Cervera 1993). Since formal V & V is performed against an initial set of specifications, there is a need for formal specifications as well as the definition of acceptability criteria of a KBS. V & V methodologies from conventional software engineering (Sommerville 1993) can also be adapted for KBS. There is nonetheless a lack of widely accepted KBS life-cycle protocol that establishes which V & V activities can be used and when such activities can be performed. The methods and results used in the validation of Tall-D system are reported here, with emphasis on the work with external experts participation.

2.1 Validation methodology for Tall-D

Two methods were used in the V & V of the Tall-D system: (i) incremental verification by random output checking, followed by (ii) validation by external experts. Since the development of Tall-D was not initiated with formal specifications, verification against such a set of specifications did not come into consideration. Tall-D was checked in an incremental manner, as a portion of source code or module was developed. It was a cyclic process in which coding, checking and debugging were performed by the developer. Random output checking by using features of the KBS development tool such as break-point, tracing of firing of rules, explanation function and inspection of objects was part of the routine development and debugging process. Then followed validation performed in collaboration with an expert architect and an expert structural engineer, which forms the focus of this presentation.

3 Validation by external experts

The objective of validation by external experts is to test the Tall-D system with leading designers from the industry who are familiar with the practical aspects of multi-storey building design. The two experts that volunteered their time and project information to evaluate Tall-D were Mr. Antony Niro and Mr. Serge Vézina. Both have extensive experience in the design of multi-storey office buildings. Mr. Niro is an architect consultant (Di Miele Niro Architects, Montreal). Mr. Vézina is a structural engineer at Lalonde, Valois, Lamarre, Valois inc., Montreal, a subsidiary of SNC-Lavalin.

Mr. Vézina selected his recent tall building design, the 1000 de La Gauchetière. Though it represented the high end of the height limitations for Tall-D (50 storeys), it was a successful interactive session that resulted in alternative designs from Tall-D as well as it presented the features of the design system to the expert.

In the other session with Mr. Niro, Place du Canada and IBM-Marathon office towers in Montreal were the test-cases. One common feature of test-cases is that they are all office towers, mostly prismatic with rectangular or square floor plans.

Due to the restrictions on space, not all three test-cases could be presented. One of the three test-cases, the IBM-Marathon building, is presented in a moderate amount of detail as a representative case. For a more comprehensive description of the test-cases and discussion of results the reader is referred to Ravi (1998).

3.1 Design case: IBM-Marathon building

This building is forty seven storeys tall including four mechanical levels. The building has a main tower and two low rise annexes attached to the main tower. This test-case is studied considering only the main tower. The base dimensions of the main tower are 60mx30m. The core to window line distance (column free) is 13.7m. The core dimensions are 30mx9m. Figure 1 shows a typical floor plan of the building under consideration. The design input to generate possible solutions by Tall-D is shown in Table 1. Of the twenty nine alternatives initially generated, twenty three were retained for ranking. Among the evaluated alternatives, Layout#24 ranked second, and due to the number of storeys being forty eight and close to the actual forty seven, is selected by the expert to proceed and inspect the geometry.

After perusal of the structural configuration for Layout#24, and since the plan dimensions of Layout#24 (45m x 40 m) are not close to that of the test-case (which is 60m x 30 m), another alternative Layout#22 ranked third with rectangular floor plan dimensions (55m x 35m) closer to test-case than those of Layout#24, is selected to proceed with geometric configuration and structural design. Figure 2 shows a structural configuration for Layout#22. Different lateral system alternatives are generated by Tall-D. In all, four alternative structural system schemes are generated each with geometric information. Each scheme has alternative column spacing on the perimeter. The four types of structural schemes generated are described below, in no particular order:

a) All-concrete, frame shearwall scheme. A system that combines shearwalls and rigid frames to provide adequate lateral-load resistance for tall buildings. The actual building uses this system.
b) Steel framed tube with concrete shearwall. Closely spaced columns on the perimeter along with a shearcore provides great flexibility to design for lateral loads for a tall building like this one.
c) All-steel, braced perimeter frames on the exterior faces of the building. Provides greater flexibility for planning occupant space as opposed to the next scheme of interior braced frame.
d) All-steel, braced frames on the interior. The bracings are on the inside where they are easier to conceal. However if large open spaces or greater flexibility is needed, this may not be a suitable choice.

The details of the column sizes and quantities for the above first two schemes for each column spacing alternative are generated by Tall-D and inspected the expert. The other two alternatives being all-steel structural schemes were not inspected by the expert. Two other structural systems are identified by Tall-D as suitable for use in these buildings, but did not complete the design due to the incomplete state of their implementation. These two are framed end channel scheme and belt truss with braced frame scheme. When the percentage of core area (with respect to gross floor area) is reduced to 15% from the previous 20% as suggested by the expert designer, Tall-D produced an additional alternative (labelled here Layout#23 with plan dimensions 55mx30m and 49 storeys) which is yet closer to the test-case dimensions.

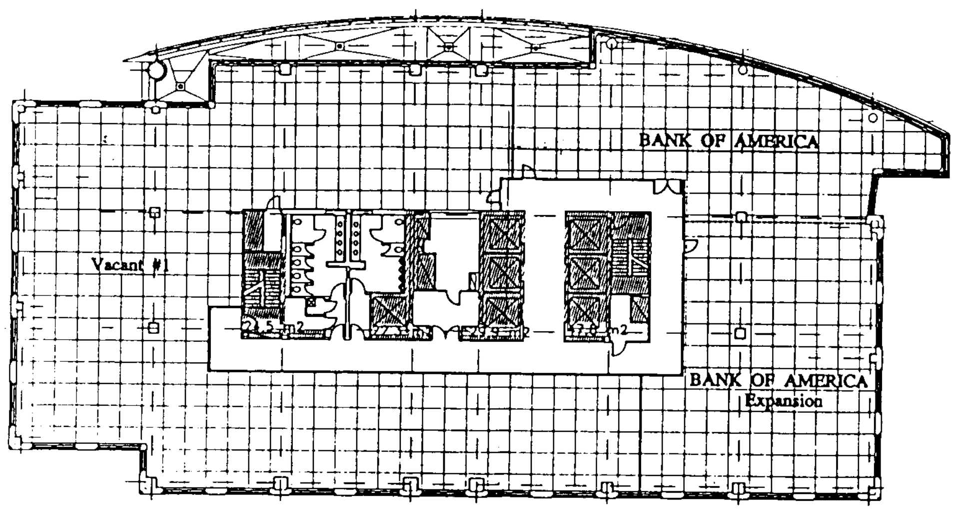
Table 1: Input parameters for example design-case

Parameter	Value
Net Floor Area required	65790 m^2
Maximum number of floors	50
Dimensions of Plot	130 x 70 m
Approximate Budget [1995$]	$200 millions

Table 2 shows a comparison between the as-built design parameters on the left and the Tall-D generated parameters on the right - Layout#22. For purposes of comparison with the actual building the values for frame-shrearwall scheme for the alternative with perimeter column spacing of xx:6.9m and yy:7.0m are used. The sizes of the structural members as well as the spacing of columns are comparable between the test-case and as designed by the Tall-D system. Tall-D has selected a concrete compressive strength of 60MPa for the initial layout selection Layout#24. The columns are spaced at 7.5m with square sizes of 850mm at base and 450mm at 35th floor. Since the expert preferred the rectangular proportions of Layout#22 the rest of the design was carried out for the same. The corresponding Tall-D designed values for Layout#22 are 55MPa, 6.9m column spacing, square column sizes of 850mm at base and 350mm at the 35th floor. The corresponding actual values are 55MPa concrete, 9m column spacing, sections of 1000mm at base and 600mm at 35th floor (according to the external expert). The somewhat smaller sections of columns for Tall-D design can be attributed to the smaller spacing suggested by Tall-D. The smaller clear span of 9.7m in the design simulation as opposed to the actual value of 13.7m would also impose lesser gravity loads on the perimeter columns, though the occupant space is also less. It can therefore be said that Tall-D columns appear reasonably sized.

Comparing the quantities for the different alternatives, one can find a range of quantities. Though these material quantities are for the lateral-load resisting system alone, they are an indication of the footprint of the structure. It can be said with some degree of confidence that the relative measure of these quantities are an indication of the material costs. Though material costs are not always the binding factor in the selection of a system, all things being equal this factor can certainly be used to select an alternative from those presented by Tall-D. As an example, the alternatives with perimeter column spacing of 4.6m and 4.4m have 143 m^3 and 177 m^3 less concrete volume than the two subsequent alternatives respectively (column spacing 6.9m / 7.0m and 6.1m / 5.8m). Similarly for the steel framed tube alternative the steel tonnage for the columns alone ranges from a low of 261 tonnes to 504 tonnes which makes the alternative with the perimeter column spacing of 7.9m and 8.7m the preferred alternative as opposed to 4.5m or 3.0m perimeter column spacing. The quantities are better used as a relative measure than an absolute conclusive parameter. Thus Tall-D generated material quantities provide an evaluation of the structural systems generated, and is appropriate for preliminary design purposes.

Ranked first among the gravity system alternatives for the frame shearwall structural system generated by Tall-D is the concrete joist slab system with a total depth of 1100mm inclusive of joist depth 400mm. The other alternatives are, in order, waffle slab, one-way slab with beams,



IBM-Marathon Building	Year Built: 1992
1250 boulevard René-Lévesque	Plan Dimensions: 60mx30m
Montreal	Sketch not to scale
Source: Excerpt from space planning drawings (A. Niro, Architect)	

Fig. 1: Typical floor plan (level ten) of IBM-Marathon building

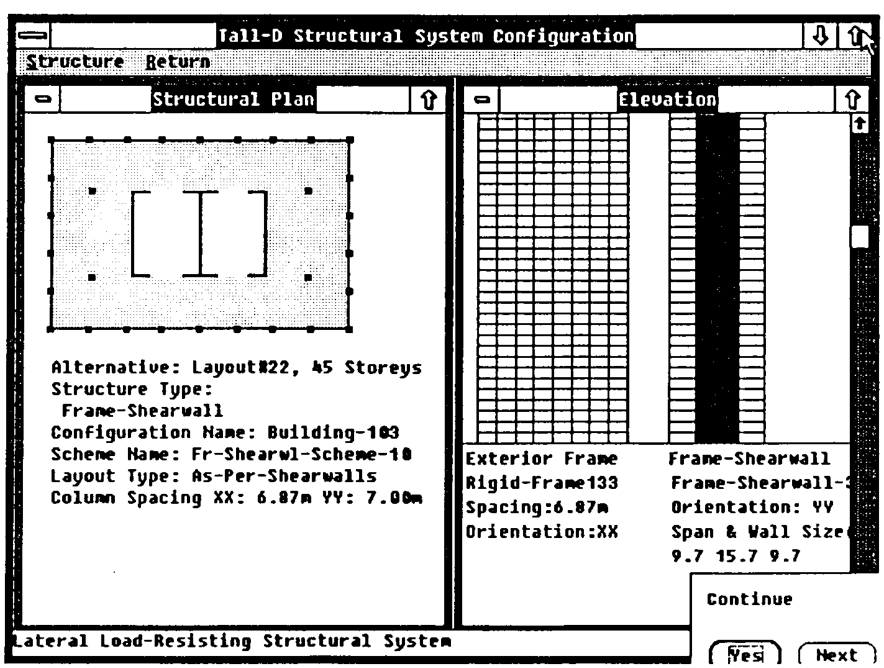


Fig. 2: Structural configuration alternative for Layout#22 of design-case

Table 2: Comparison of as-built IBM-Marathon building with Tall-D design

Building Parameter		As Built(Tower)		Tall-D (Layout#22)	
Plan dimensions		60m x 30m		55m x 35m	
Core dimensions		30m x 9m 16-35floors	41m x 9m 1-15 floors	24.6m x 15.7m	
Storeys (+mechanical levels)		43 (+4)		43 (+ 2)	
Floor area Gross::Net (m^2)		84600 :: 65790		86625 :: 66168	
Cost of building ($ millions)		(148[1])		72	
Lateral-load resisting system		Frame-Shearwall		Frame-Shearwall[2]	
Material grade of columns		55MPa		55Mpa	
Column spacing on perimeter		*Front:xx*	*Side:yy*	*Front:xx*	*Side:yy*
		9.0m	7.5m	6.87m	7.00m
Column sizes on building perimeter (mxm)	Ground level	1.0 x 1.0	1.0 x 1.0	.85 x .85	.85 x .85
	Levels 15-11	n/a	n/a	.75 x .75	.75 x .75
	Levels 25-21	n/a	n/a	.65 x .65	.65 x .65
	Level 35	0.6 x 0.6	0.6 x 0.6	.35 x .35	.35 x .35
	Levels 48-46	n/a	n/a	.30 x .30	.30 x .30
Number of shearwalls		6 at Base; 4 at 43rd Floor		3 throughout	
Shearwall concrete, size and thickness		60MPa; 9m long; 525mm		55MPa; 15.7m; 600mm	
Gravity-load resisting system		n/a		Concrete Joist slab and others (see p. D2-11)	
Clear span (front/back and sides)		13.7m⇳ and 15.0m⇔		9.7m⇳ and 15.2m⇔	
Depth of gravity system beams		n/a		1.10m for joist beam-slab system	

band-beam with slab and finally hollow core slab. The ranking is based on known in-place cost of construction (Means 1996), not on estimated quantities nor on other merits of the gravity systems. Similar rankings for the steel framed tube schemes are, again, in order of preference, truss beam, haunch beam, tapered beam, parallel beam and stub girder. The truss beam is 680mm deep with additional steel deck 70mm thick as well an equal depth of concrete topping.

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[1] This cost includes the tower, low-rise part, under-ground parking, site preparation etc.; Tall-D cost is only that of the tower, above ground. The actual cost for the as-built tower is 90 million.

[2] Information on all structural systems alternatives proposed by Tall-D could not be presented due to limitations on space.

4 Questionnaire-based evaluation of Tall-D

A questionnaire with 40 different queries categorised under seven headings was used to elicit an assessment of Tall-D from the experts. The questionnaire along with the expert evaluations is shown in Table 3(a) and 3(b). The scoring is based on a numeric scale of 1 to 5 with 1 being "strongly disagree" and 5 being "strongly agree". A few of the features such as member scaling for gravity load-resisting system being under-designed invited a grading of 2 from the engineer. Otherwise the system was graded favourably in all other categories. On a few items the two experts differed significantly in their assessment. On the relevance of floor plans generated - the architect scores 5 versus a 3 from the engineer. Similarly, the item - display of results - got 2 from the engineer and 4 from the architect. Apart from perceptions, one reason for this is the architect performed two designs - one of moderate height and the other much taller - compared to only one by the engineer. Therefore the former was exposed to a larger variety of configurations and corresponding number of text screens, giving a better demonstration of the feature. Barring a few items out of some 40, there is general agreement in their assessment. Both experts give 3 for approximate costs indicating it needs improvement and both are highly enthusiastic of the utility of Tall-D. The average of scores assigned by the two experts under different categories may be studied to understand Tall-D performance. The average scores show the engineer scoring from a low of 3.0 in cost and quantity to a high of 4.6 in utility of Tall-D categories. The architect scored a low of 3.6 on design process issues and user interface with the high being again utility of Tall-D with a score of 4.4. Incidentally the "Utility of Tall-D" category consists of items such as useful to perform preliminary design (both score 5), useful to explore design possibilities (again both score 5) and useful tool for multi-storey building design (scores of 5 and 4). This clearly demonstrates a principal aim of this work is realised which is the development of a tool for preliminary design. Since an architect along with an engineer considered Tall-D from their points of view and responded well, it can reasonably be said that domain integration between the architectural and structural design areas has been successfully demonstrated. Thus the process of validation of Tall-D by the experts not only served to compare practical designs to Tall-D generated designs, but was also useful to perform an overall evaluation of the computer-based tool for preliminary design tasks. It also brought out the fact that a KBS could be deployed in practice, with expert evaluation and endorsement.

5 Conclusion

Tall-D was very well received and evaluated by the two experts who were involved at this step of the validation process. A few weaknesses in Tall-D were also identified. The architect pointed out that the core size was large for relatively smaller sized buildings. For rectangular floor plans, slightly smaller clear spans were generated by Tall-D in the short-span direction (yy) of the building compared to the actual designs. A noticeable weakness in Tall-D member sizing is related to steel beams located on the building perimeter and moment-connected so as to participate in lateral load resistance. Gravity system sizing was in some cases under-designed. Gravity system designs produced by Tall-D were considered by the structural expert as adequate from the strength point of view but could be inadequate from the serviceability (structural) point of view.

Table 3(a) Comparison of the Tall-D Evaluation Scores by Expert Structural Engineer and Expert Architect.

Tall-D Evaluation Criteria	(5) Strongly Agree (1) Strongly Disagree	
	Engineer	Architect
I. *Architectural Considerations (flexibility etc.)*		
Relevance of floor plans generated	1 2 ③ 4 5	1 2 3 4 ⑤
Core location(s) appropriate	1 2 3 ④ 5	1 2 3 ④ 5
Relevance of column layouts generated	1 2 3 ④ 5	1 2 ③ 4 5
Ranking of initial floor plans	1 2 ③ 4 5	1 2 3 ④ 5
II. ***Preliminary Structural Design Considerations.***		
IIa. ***Geometric Configuration of Lateral Load-Resisting System (LLS)***		
Exploration/Generation of possible LLS alternatives	1 2 3 ④ 5	1 2 3 ④ 5
Compatibility of LLS with initial floor layout		
Of plans with rigid-frames	1 2 3 ④ 5	1 2 3 ④ 5
Of plans with braced-frames	1 2 3 ④ 5	1 2 3 ④ 5
Of plans with shearwalls	1 2 3 ④ 5	1 2 3 4 ⑤
Of plans with tubular structure	1 2 3 ④ 5	1 2 ③ 4 5
Concrete Column Sizing	1 2 ③ 4 5	1 2 3 ④ 5
Steel Column Sizing	1 2 ③ 4 5	1 2 3 ④ 5
Concrete Shearwall Sizing	1 2 ③ 4 5	1 2 3 ④ 5
IIb. ***Geometric configuration of Gravity Load-Resisting System (GLS)***		
Exploration/Generation of Relevant alternatives	1 2 3 ④ 5	1 2 3 ④ 5
Concrete beam sizing	1 2 ③ 4 5	1 2 3 ④ 5
Steel beam sizing (rolled sections, stub girders, castellated, haunch, tapered beams, joist/truss etc.)	1 ② 3 4 5	1 2 3 ④ 5
Concrete slab sizing (flat-slab, waffle, joists, oneway and twoway slabs etc.)	1 ② 3 4 5	1 2 3 ④ 5
Steel deck-slab sizing	1 ② 3 4 5	1 2 3 ④ 5

Table 3(b). Comparison of the Tall-D Evaluation Scores by Expert Structural Engineer and Expert Architect.

Tall-D Evaluation Criteria	Engineer	Architect
III ***Design Process Issues and User Interface for Tall-D***		
Consideration of relevant constraints	1 2 (3) 4 5	1 2 3 (4) 5
Ability to redefine criteria	1 2 3 (4) 5	1 2 (3) 4 5
Ability to go back to generate different schemes	1 2 3 (4) 5	1 2 3 (4) 5
Sketch Floor Layout Graphical Display	1 2 (3) 4 5	1 2 (3) 4 5
Structural Elevation Graphical Display	1 2 3 (4) 5	1 2 (3) 4 5
Display of Results - Text Screens	1 (2) 3 4 5	1 2 3 (4) 5
Explanation of Results	1 2 (3) 4 5	1 2 3 (4) 5
Clarity of Menus and prompts	1 2 (3) 4 5	1 2 3 (4) 5
IV ***Approximate Analysis of frames for lateral loads***		
Rigid Frame system	1 2 3 (4) 5	1 2 3 (4) 5
Braced frame system	1 2 3 (4) 5	1 2 (3) 4 5
Frame-Shearwall system	1 2 3 (4) 5	1 2 3 4 (5)
Tubular frame system	1 2 (3) 4 5	1 2 3 (4) 5
V ***Cost and Quantity Estimation***		
Approximation of overall project cost	1 2 (3) 4 5	1 2 (3) 4 5
Relative structural cost of vertical structuarl system	1 2 (3) 4 5	1 2 3 (4) 5
Relative structural cost of floor system	1 2 (3) 4 5	1 2 3 (4) 5
Structural quantities estimation	1 2 (3) 4 5	1 2 3 4 (5)
VI ***Utility of Tall-D***		
Overall concept of System	1 2 3 (4) 5	1 2 3 (4) 5
Useful to perform preliminary design	1 2 3 4 (5)	1 2 3 4 (5)
Useful tool for multistorey buildings design	1 2 3 4 (5)	1 2 3 (4) 5
Useful to explore design possibilities	1 2 3 4 (5)	1 2 3 4 (5)
Useful as learning tool for students	1 2 3 (4) 5	1 2 3 (4) 5
Overall performance	1 2 3 (4) 5	1 2 3 (4) 5

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