Visual Basic Interface for Size & Shape Optimization of Space Trusses using BB-BC algorithm

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Abstract— **Most of the commercially available softwares include size optimization feature for a given truss topology. Repetitive analysis and designs are automated. However, shape optimization involves successive model creation for analysis and design. In routine design applications, it is too cumbersome to process the information gathered from different alternatives.**

In the present study, an attempt is made for seamless integration of size and shape optimization process for 2D and 3D Truss systems. The present study is aimed at design optimization of trusses considering its weight or volume, thus resulting in overall reduction of the project cost using BB-BC algorithm (Big Bang-Big Crunch). The algorithm can select Indian Standard Angle sections based on structural requirements, practical constraints such as availabilty of sections, fabrications and constructabaility. Shape optimization is achieved as per the suggested constraints for changing the geometrical dimensions for a known intrinsic shape also known as topology.

The process of size and shape optimization is automated using "Visual Basic Application" in Microsoft Excel environment using "STAAD.Pro" for analysis and AutoCAD for drafting purposes. The Interface acts as host for both the softwares and is developed using OpenSTAAD and OpenCAD objects library. The VBA interface updates the optimized shape in the STAAD.Pro environment. It is also possible to create BOQ of the optimized model along with general alignment drawings in AutoCAD.

The process and the techniques pursued in the present study are used to provide optimized solutions for a 25 bar space truss, 72 bar space truss and a 2D industrial roof truss. All options such as size optimization of individual members, group optimization and Shape and Size optimization are tested. Results are compared with STAAD.Pro. The approach is found to be quite competitive for optimization studies.

Keywords—size optimization, shape optimization, OpenSTAAD, OpenCAD, BB-BC : Big Bang – Big Crunch

I.   INTRODUCTION

In any structure involving steel, material cost, fabrication cost and erection cost become the governing factors for the project cost. So, minimizing the weight becomes significant in any structural design. Cost minimization can be achieved by optimizing the weight, volume or the geometry of the truss system. Such reduction in materials serves as an engineered initiative for sustainable design.

Most of the commercially available softwares include size optimization feature for a given truss topology. Repetitive analysis and designs are automated. However, shape optimization involves successive model creation for analysis and design. In routine design applications, it is too cumbersome to process the information gathered from different alternatives.

In the present study an attempt is made for seamless integration of size and shape optimization process for 2D and 3D Truss systems. The process of size and shape optimization is automated using "Visual Basic Application" (VBA) in Microsoft Excel environment using "STAAD.Pro" for analysis and "AutoCAD" for drafting purposes. The Interface acts as host for both the softwares and is developed using Open STAAD and OpenCAD objects library.

The (BB–BC) Optimization method generates random points in the Big Bang phase and shrinks these points to a single representative point via a center of mass in the Big Crunch phase. After a number of sequential Big Bangs and Big Crunches where the distribution of randomness within the search space during the Big Bang becomes smaller and smaller about the average point computed during the Big Crunch, the algorithm converges to a solution[1].

II.   VBA INTERFACE

Fig. 1 shows the VBA interface for size and shape optimization of truss. There are two option buttons. "Individual member optimization" and "group optimization". The user has to select any one of these for starting the optimization process. Group optimization is possible if a group definition is made in STAAD.Pro at the time of modeling.

There are ten text boxes in the interface, which takes the input from the user for shape optimization. The user has to specify node number, the direction and distance the node is to be translated and the desired interval for each translation. With this information, different truss configurations are generated. The user can add, update or delete an input set by selecting it from the listbox.

Table 1 shows the command buttons in the interface and the task performed by them. There are two option buttons. "Individual member optimization" and "group optimization".
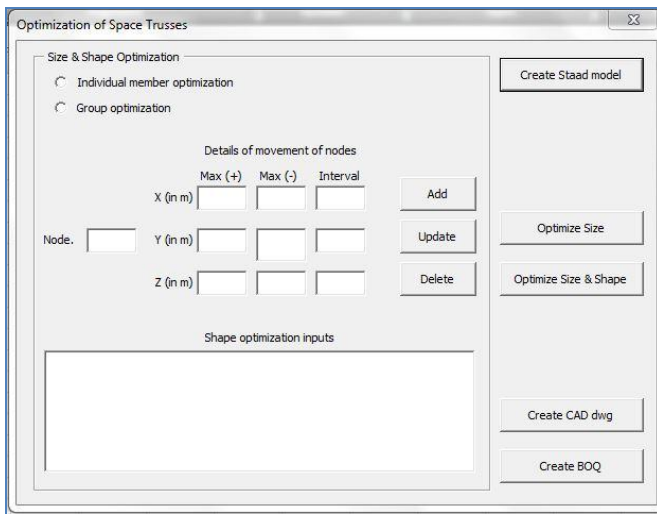

Fig 1. VBA Interface

A. "CREATE STAAD MODEL" BUTTON

The first command button in the interface is "Create Staad model". Clicking this button invokes the STAAD.Pro application and shows the application window to the user. New model or editing an existing model can be done using STAAD.Pro preprocessing features.

Table 1. Command buttons & their tasks

Sl. No.	Command button	Task
1	Create STAAD model	Opens STAAD.Pro application for creating model.
2	Add	Adds a shape optimization input set.
3	Update	Updates the selected input set from listbox.
4	Delete	Deletes selected input set from listbox.
5	Optimize size	Performs size optimization of the truss.
6	Optimize shape	Performs size & shape optimization of the truss.
7	Create dwg	Creates an AutoCAD drawing of the optimized model.
8	Create BOQ	Creates BOQ of the optimized model.

Member Lengths, and nodal coordinates must be in meters and the loads have be specified in Kilo-Newtons. The user must renumber the nodes and members from 1 to n in order. This is necessary as the VBA program written in the present study is designed to loop from 1 to n number of nodes or members during the optimization process. Renumbering is a simple step in STAAD.Pro and can be done easily. Upon completion of FE model in all aspects, user has to invoke Run Analysis with PrintAll options. Upon successful execution, control returns to VBA interface to specify inputs for optimization.

B. "OPTIMIZE SIZE" BUTTON

Click this button to perform size optimization of the truss model, which is open in STAAD.Pro application. Following is the checklist to be completed before clicking this button.

- ✓ To initiate the optimization process, the user has to select an option between individual member optimization or group optimization.
- ✓ Analysis has been done successfully in STAAD.Pro environment.

With option individual member optimization, each member in the truss will be optimized and sections will be assigned accordingly. In most of the cases individual member optimization is not practical. Group optimization option is useful in this regard.

The VBA interface identifies the number of groups and members associated with them. Designs are done for all the members in that group. All the members in that group are assigned with maximum section size obtained during group design. Following checklist is to be completed before Group optimization option is invoked.

- ✓ Groups definition must have been completed in STAAD.Pro.

After the size optimization is performed, results are tabulated in the Excel worksheet named "Results". The results sheet provides information about member number and the respective optimized section assigned to it. It also gives the weight of the structure. "BOQ" command button can then be clicked to get result in Excel worksheet named "BOQ".

C. "OPTIMIZE SIZE AND SHAPE" BUTTON

The command button "Optimize size and shape" performs both optimization process. This is the focus of the present study. Both options such as individual member and group optimization are available. For optimizing shape some input data about the shape changes in the truss is necessary. Following checklist is to be completed before invoking this optimization process.

- ✓ node number which are intended to be moved,
- ✓ the direction in which they have to be moved,
- ✓ distance by which they have to be moved,
- ✓ and the desired interval in which the nodes have to be moved.

Typical input details in the interface to successfully complete shape optimization are indicated in Fig. 2.

The textbox at the leftmost part takes node number as input. The 3x3 matrix of textboxes take details of node movements as inputs for distances to be moved in X, Y and Z direction of that node. For each direction, the interval of movement of nodes is to be specified. Based on this input, VBA interface will decide the number of shapes that will be analyzed in this optimization process.

The "Add" command button adds the information from ten text boxes to the listbox at the bottom. All the textboxes have to be filled in order to add the input set to the listbox. If a specific node is not moving in a particular direction, the respective value should be entered as zero and should not be left blank. Also the program is smart to show a warning message if same node is added more than once.

The interface allows the user to edit the input information at any stage of input. For this the user has to select the input set from the listbox which requires editing. This will bring up that input set in the respective textboxes. After editing, the "Update" command button has to be clicked to save the changes. The changed values are automatically updated in the listbox.

"Size and Shape optimization" process is designed to work as mentioned below.
1. The data in the listbox are read by the VBA program and the program calculates the number of shapes to be analyzed.
2. The program then calculates the nodal coordinates of each shape from the input data and updates the structure in STAAD.Pro. The change in the shape of the structure can be viewed in STAAD.Pro in real-time.
3. At this stage, a command button "Perform analysis" appears in the VBA interface.
4. If the shape change in STAAD.Pro is correct, click "Perform analysis".
5. VBA program optimizes the structure in terms of sectional areas. This process is repeated for all the shapes specified and the output is presented in Excel worksheets.

Fig 2. Shape Optimization Input set

D. " CREATE CAD DWG" BUTTON

After the optimization is performed AutoCAD drawing of the optimized model can be created at the click of this button. This is accomplished by using the OpenCAD function available in AutoCAD similar. Here AutoCAD is called as an object in VBA and all the commands in AutoCAD can now be controlled from VBA with relevant syntaxes. Each member from the optimized model is considered and the coordinates of the start node and end nodes are read from STAAD.Pro and the member is drawn in AutoCAD.

E. " CREATE BOQ" BUTTON

The VBA interface also provides an option for creating BOQ of the optimized model. These results are presented in the worksheet named "BOQ". The BOQ provides information about name of the section, length of the members, weight of each type of section and the quantity. The BOQ is prepared according to individual member or group optimization selection.

F. SUMMARY

Through this interface following four choices for optimization are available
1. Individual member size optimization.
2. Group size optimization.
3. Individual size and shape optimization.
4. Group size and shape optimization.

Through OpenSTAAD and OpenCAD functions, this VBA interface virtually results in a seamless integration of industry standard softwares such as STAAD.Pro and AutoCAD. VBA interface developed during this study has program segments to perform optimization of truss systems based on BB-BC algorithm and design of members as per IS 800 using Limit state design principles.

III.   CASE STUDY AND RESULTS

A. SIZE OPTIMIZATION OF 25 BAR SPACE TRUSS

The VBA interface developed is used to optimize three truss examples both in terms of size and shape. One 2D roof truss and two space trusses are considered for the optimization. For each truss, the results are compared with STAAD.Pro application results. Also, different topologies are considered for shape optimization. The results of optimization for each truss are also tabulated.

Fig. 3 shows the 25 bar spatial truss used for optimizing size and shape. Table 2 shows the loading details on the truss & Table 3 shows the group definition considered in STAAD.Pro application while modeling.

The truss is first analyzed for size. Both individual member and group optimization is carried out. Initially the members are assigned a minimum section of ISA 20x20x3 to carry out the analysis in STAAD.Pro. The results from the VBA interface are tabulated in Tables 4 and 5 and are compared with results from STAAD.Pro application.
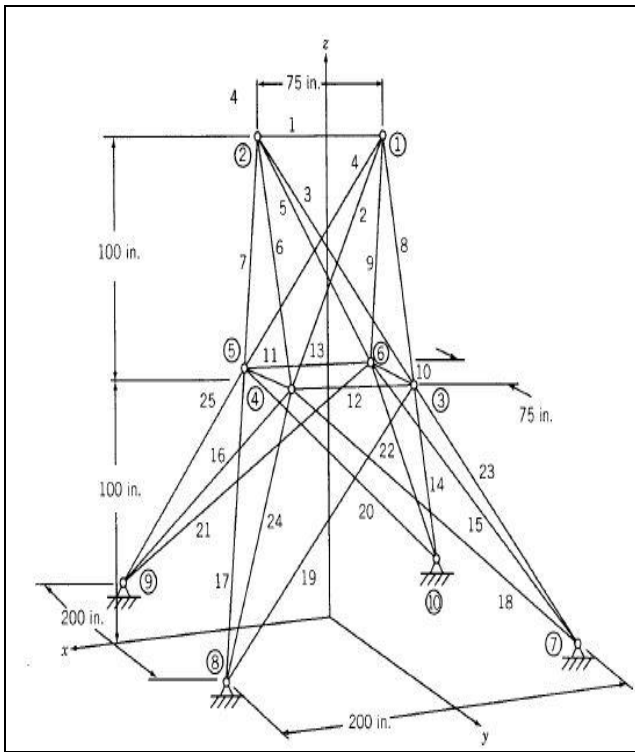
Fig 3. 25 bar spatial truss

Table 2. Loads on 25 bar space truss

Node No.	Load
1	400 KN (↓)
2	400 KN (↓)

3. Group definition of 25 bar space truss

Group Name	Members
_01	1
_02	2 to 5
_03	6 to 9
_04	10 & 11
_05	12 & 13
_06	14 to 17
_07	18 to 21
_08	22 to 25

Table 4. Individual member size optimization of
25 bar truss

Member No.	Optimized section	
	VBA Interface	STAAD.Pro
1	ISA40X40X5	ISA45X45X6
2	ISA30X30X3	ISA30X30X3
3	ISA30X30X3	ISA30X30X3
4	ISA30X30X3	ISA30X30X3
5	ISA30X30X3	ISA30X30X3
6	ISA125X95X10	ISA150X115X10
7	ISA150X150X10	ISA150X150X10
8	ISA125X95X10	ISA150X115X10
9	ISA150X150X10	ISA150X150X10
10	ISA150X150X10	ISA150X150X10
11	ISA125X95X10	ISA150X115X10
12	ISA150X150X10	ISA150X150X10
13	ISA125X95X10	ISA150X115X10
14	ISA150X150X10	ISA150X150X10
15	ISA150X150X10	ISA150X150X10
16	ISA150X150X10	ISA150X150X10
17	ISA150X150X10	ISA150X150X10
18	ISA100X100X12	ISA130X130X8
19	ISA100X100X12	ISA130X130X8
20	ISA100X100X12	ISA130X130X8
21	ISA100X100X12	ISA130X130X8
22	ISA100X100X6	ISA125X95X6
23	ISA100X100X6	ISA125X95X6
24	ISA100X100X6	ISA125X95X6
25	ISA100X100X6	ISA125X95X6
Weight (kg)	14248	13836

Table 5. Group size optimization of 25 bar truss

Group Name	Optimized section	
	VBA Interface	STAAD.Pro
_01	ISA40X40X5	ISA45X45X6
_02	ISA100X100X6	ISA125X95X6
_03	ISA100X100X12	ISA130X130X8
_04	ISA30X30X3	ISA30X30X3
_05	ISA30X30X3	ISA30X30X3
_06	ISA150X150X10	ISA150X150X10
_07	ISA150X150X10	ISA150X150X10
_08	ISA125X95X10	ISA150X115X10
Weight(kg)	16561	16321

B. SHAPE OPTIMIZATION OF 25 BAR SPACE TRUSS

The different shapes considered in the optimization are shown in the Fig 4. Note that only selected nodes are moved to get different shapes.
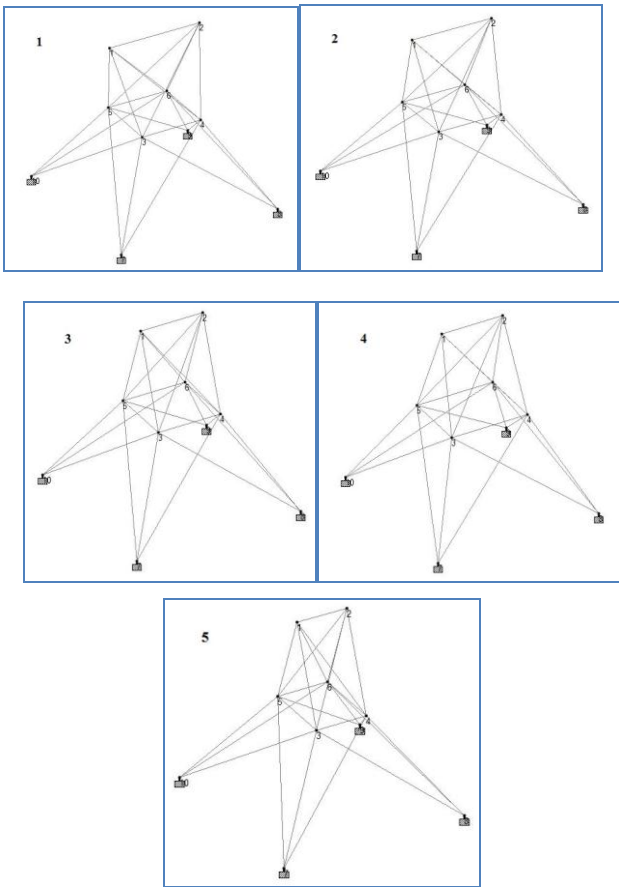

Fig 4. Topologies created for shape optimization

Table 6. Nodal coordinates of different shapes of 25 bar space truss

Topology	Node No.	X	Y	Z
1	1	13.71	5.08	-7.42904
	2	16.615	5.08	-7.42904
2	1	13.96	5.08	-7.42904
	2	16.365	5.08	-7.42904
3	1	14.21	5.08	-7.42904
	2	16.115	5.08	-7.42904
4	3	13.96	2.54	-6.47654
	5	13.960	2.54	-8.38154
	4	16.365	2.54	-6.47654
	6	16.365	2.54	-8.38154
5	3	14.210	2.54	-6.47654
	5	14.210	2.54	-8.38154
	4	16.115	2.54	-6.47654
	6	16.115	2.54	-8.38154

Table 7. Shape optimization results of 25 bar space truss

Topology	Optimized weight (kg)
1	17167
2	16650
3	16561
4	15979
5	15337

Table 8. BOQ of 25 bar truss – Topology 5

Section	Length (m)	Weight (kg)	Qty	Total weight (kg)
ISA30X30X3	1.905	25.70	5	128.53
ISA200X150X10	3.390	899.03	4	2996.11
ISA150X150X10	4.601	1041.82	8	8202.06
ISA200X150X10	2.713	719.49	4	2253.62
ISA125X95X8	3.315	439.05	4	1756.20
Cumulative weight (kg)				15337

Table 6 shows the nodal coordinates of different topologies considered based on the shape optimization input by the user. For the first three topologies, coordinates of node 1 and 2 are varied and for the other two topologies nodes 3, 4 and 5 are moved.

Table 7 shows the result of the shape optimization process. The interface gives optimized weights of different topologies as the final result, thus suggesting the optimized shape for the given truss. In the present example, topology 5 with weight 15337 kg is the optimum shape for the 25 bar space truss based on the inputs by the user.

Table 8 shows the BOQ of the space truss with optimized shape. The user clicks the command button "CREATE BOQ" to create the BOQ which is presented in a Excel worksheet.

IV. 72 BAR SPACE TRUSS & 2D ROOF TRUSS

The optimization process is carried out for a 72 bar spatial truss (Fig. 5) and a 2D industrial roof truss (Fig. 6). The results obtained are tabulated in Table 9 and Table 10 respectively.

Figure 5. 72 bar space truss

Table 9. Group optimization of 72 bar space truss

Group Name	VBA Interface	STAAD.Pro
_VERTICALS	ISA200X200X15	ISA200X200X15
_BEAMS	ISA50X50X3	ISA40X40X3
_DIAGONALS	ISA125X75X10	ISA130X130X8
Weight (kg)	26311	25588

Figure 6. 2D roof truss

Table 10. Group optimization of 2D roof truss

Group Name	Optimized section	
	VBA Interface	STAAD.Pro
TOP_RAFTER	ISA200X100X15	ISA200X100X15
BOTTOM_CHORD	ISA90X90X8	ISA90X90X8
STRUTS	ISA45X30X4	ISA45X30X4
REST	ISA200X100X10	ISA200X100X10
Weight (kg)	12752	12752

V.   CONCLUSION

The optimization of trusses holds an important position in the field of structural design. In the present study, size and shape optimization of trusses has been carried out. A VBA interface was developed which could handle both size and shape optimization simultaneously.

The conclusions drawn from the project are:

1. The size optimization results from VBA interface show around 2% to 3% increase in the weight of the truss compared to results from STAAD.Pro.

2. The VBA interface is user friendly and customized to handle both size and shape optimization of trusses in a seamless environment.

3. This in-core procedure reduces the post processing time and reports all the results for verification in a single file. This feature is extremely useful in a routine design scenarios involving multiple truss configurations with large number of elements and complex geometries.

4. The post processing features such as BOQ and General alignment (GA) drawings in AutoCAD are very useful for initial estimates and production of fabrication drawings.

REFERENCES

[1] A. Kaveh and S. Talatahari "Size Optimization of Space Trusses using Big Bang-Big Crunch algorithm" (2008).

[2] Behrooz Hassani, Mostafa Assari, Morteza Kazemi Torbaghan, "Big Bang – Big Crunch Algorithm For Size Optimization of Trusses", 9th International Congress on Civil Engineering, May 8-10, 2012.

[3] Makoto Ohsaki and Colby C. Swan presented on a paper on "Topology and Geometry Optimization of Trusses and Frames".

[4] A. Kaveh and S. Talatahari, "Big Bang – Big Crunch Algorithm For Optimal Design Of Skeletal Structures" Asian journal of civil engineering (building and housing) vol. 11, no. 1 (2010).

[5] Ali Kaveh and Seyed Mohammad Javadi presented on a paper on " An efficient hybrid particle swarm strategy, ray optimizer, and harmony search algorithm for optimal d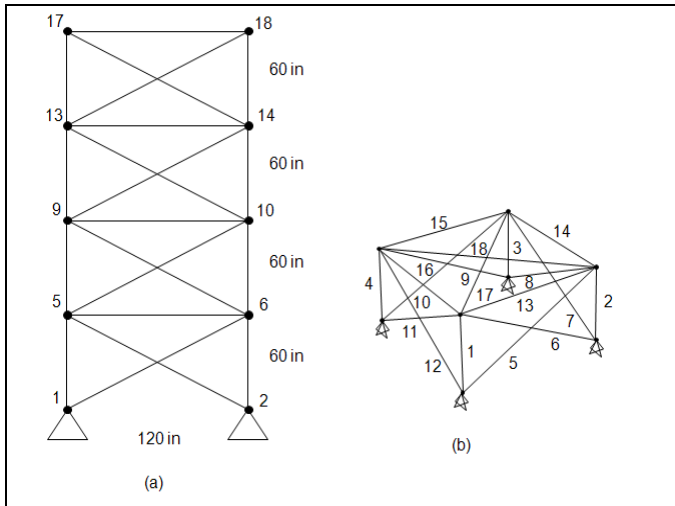esign of truss structures" in periodica polytechnica (2013).