Bulletin of the *Transilvania* University of Braşov
CIBv 2014 • Vol. 7 (56) Special Issue No. 1 - 2014

INTEGRATED DESIGN, THE SOLUTION FOR SAVING TIME, ENERGY, RESOURCES AND CO_2

C. POPA[1]

Abstract: *The following article presents the current problems a structural engineering office is facing, which are the short delivery time for the project and the required reduction of required material. The current practice is analysed, the modern approach is described and in the end the risks and costs of this change are analysed.*

Key words: *BIM, Interoperability, CAD/CAE, Parameters, Optimization.*

1. Introduction

The current market requires the delivery of cost-efficient structures in very little time.

A structural engineer is judged by the efficiency of his design which is translated into the bill of material he actually has to provide before finishing the project.

In the traditional method a simplified calculating with the most safe and overestimating methods and interpolation between similar projects can result in large uncompetitive quantities.

This traditional approach can lead to losing the contract in case another designer can bid with lower quantities.

The reason for this rush from the investors comes from the fact that they need to do a loan from the bank in most situations and the more the construction process take, the more interest the banks apply to the loan, thus reducing the profitability of the investment.

Another problem of the traditional design methods are the site modifications which appear due to the lack of cooperation between disciplines.

The average waste of materials on a traditional site sums up to 30% of the total of material ordered.

This problem affects more than just the investors and the final beneficiaries but also our planet.

The construction industry is responsible for creating more than 40% of the total CO2 production.

2. BIM, more than a concept?

Charles Eastman first used the term **Building Product Model** in his papers and book in the late 1970s. [1]

[1] Mechanics of Structure, Technical University of Civil Engineering

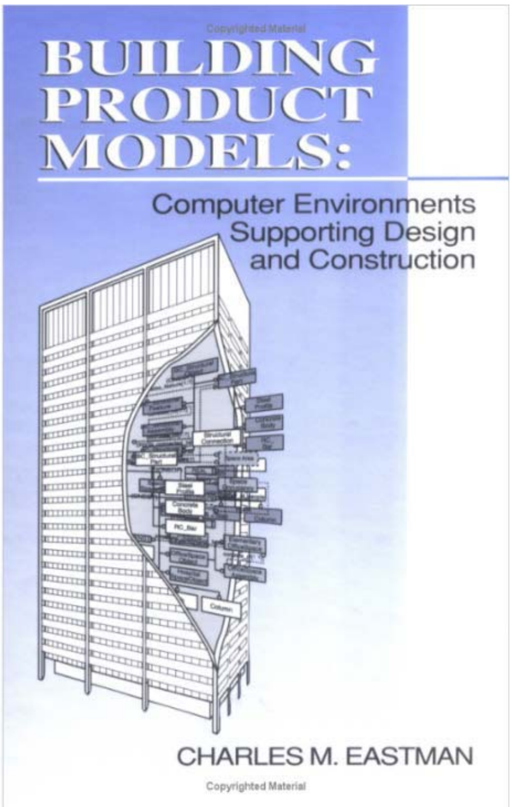


Fig. 1. *Eastman C., Building Product Models: Computer Environments Supporting Design and Construction, CRC Press, Boca Raton FL (1999).*

The term BIM, which stands for Building Information Modelling, was first coined by Jerry Laiserin, an A/E/C industry analyst and editor of the Laiserin Letter. He defines BIM as "Building Information modelling is a process of representation, which creates and maintains multidimensional, data-rich views throughout project lifecycle". [2] The objectives of BIM are the following:

- Communication
- Collaboration
- Simulation
- Optimization

In order to apply this concept in 1995 a private alliance was created which implemented a standard for CAE and CAD software in order to permit this workflow based on software operability. Thus open BIM was created along with the IFC file format.

Software providers that intended to be part of this association had to obtain a certification for the data exchange (import and export).

3. Nemetschek, a BIM solution before BIM was invented

"The future of building lies in the concerted interaction of those involved in the network"

Prof. Georg Nemetschek

Nemetschek Allplan used an integrated working method before BIM was introduced into the building industry.

It came as a software program which works on a single unique 3D model for which every discipline had a few modules with specific functions.

For examples the architects used architectural elements, the structural engineers provided the 3D reinforcement and the HVAC engineer introduced all the required elements for heating/cooling, ventilation, electrical.

After the 3D model is completed it can be checked for collisions between elements and corrected, the exact quantities can be automatically obtained.

The execution plans are obtained by generating associative views of the 3D model which can be automatically updated in case changes occur.

All the correlations are done in 3D no need for overlapping plans and doing the same modifications by every participant.

When everything is approved by the checkers and the investors the project will be ready for building, having all quantities calculated and every detail created.

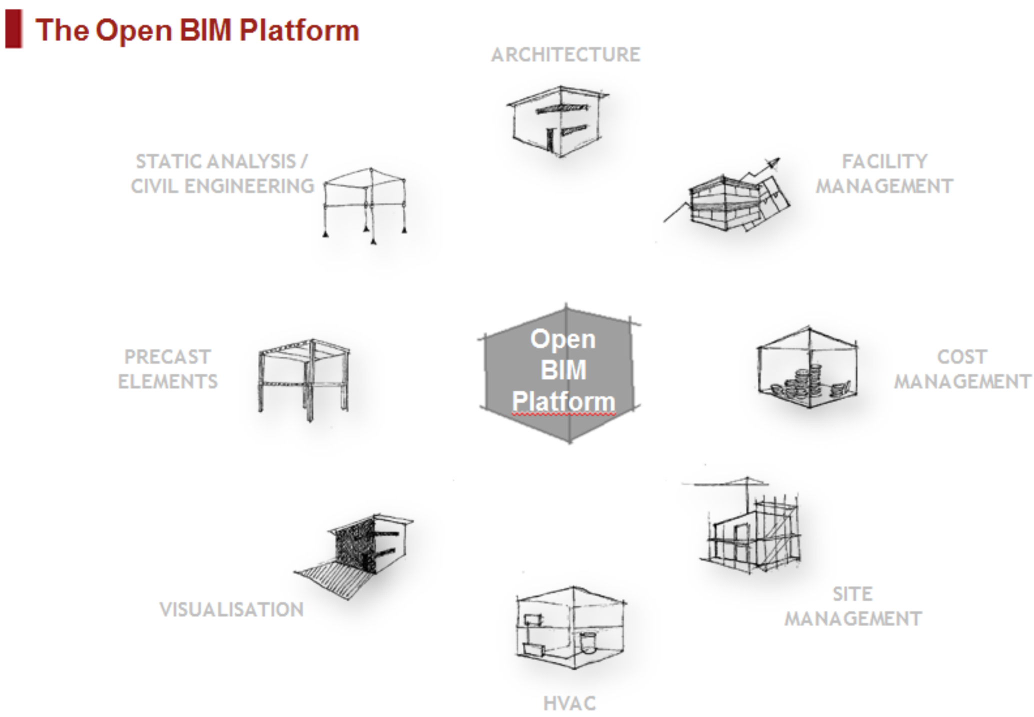


Fig. 2. *Accessing information in different ways; BIM made by Allplan*

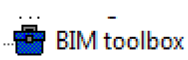
3.1. Structural model to analysis model

A major challenge for the structural engineer is to be able to calculate the 3D model designed by architect and update in with the new information and modify it should changes occur.

The problem in this field is the fact that CAD programs work with volumes, while CAE programs work with analysis lines.

An operation of aligning this calculation axes is required to be able to do the conversion from Structural Model (Architectural Model) to Analysis Model (FEM Model).

This process is called "Round-trip Engineering" and can be done, for example, between Allplan and Scia Engineer via a set of tool that belong to a special module called "BIM ToolBox".



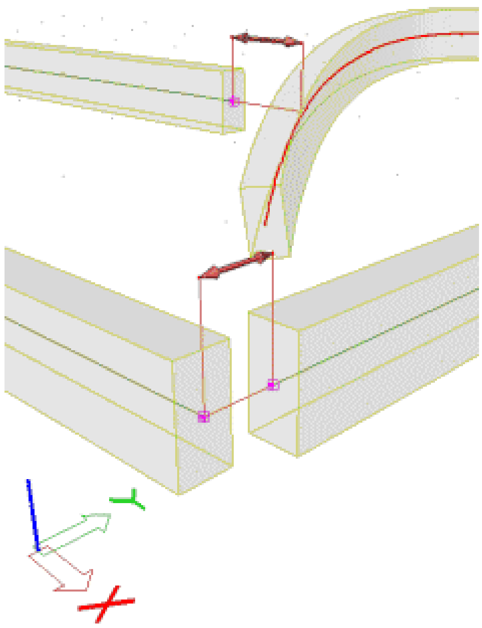


Fig.3. *Joining close axis in nodes*

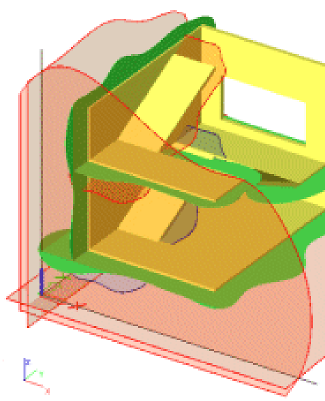


Fig.4. *Align elements to 2D elements reference plains*

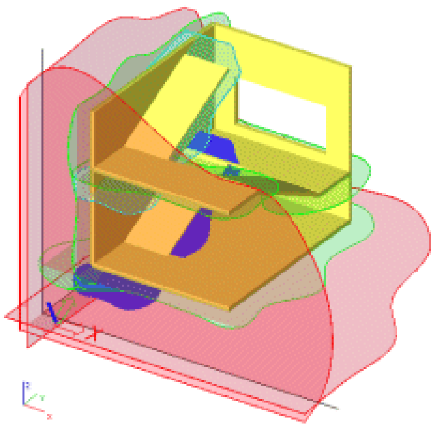


Fig.5. *Align elements to User Coordinate System*

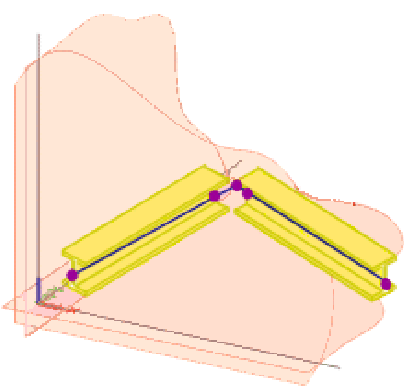


Fig.6. *Align elements to beam local coordinates system*

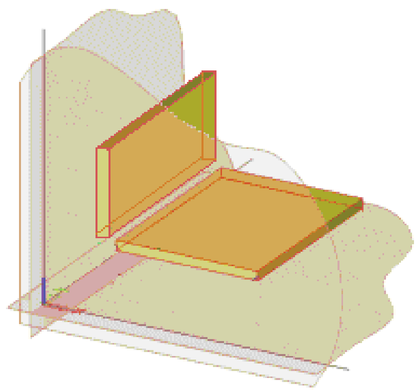


Fig.7. *Align to slab planes globally*

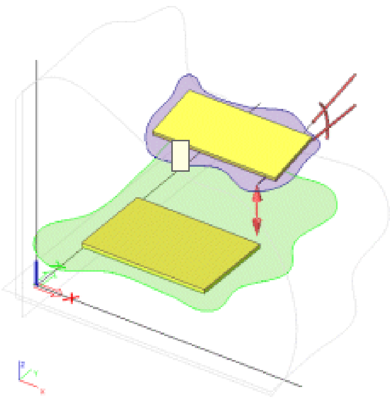


Fig.8. *Inputting the maximum angle between plates.*

3.2. Advanced FEM calculation methods

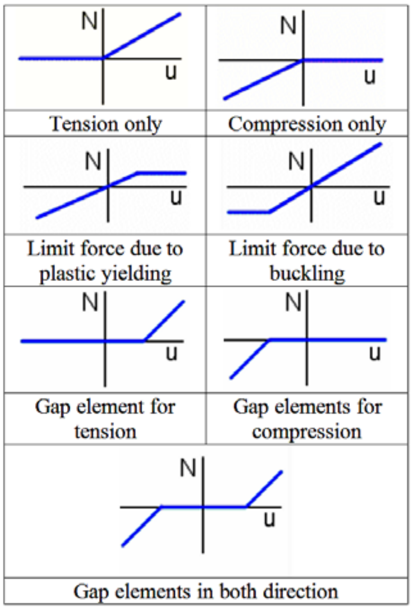
Linear calculation – The calculation is done on initial geometry and efforts and strains have an elastic distribution.

Non-Linear calculation – Here 3 types of non-linearity can be considered:

- **Geometric non-linearity** – the calculation is done on the deformed shape, second order effects are taken into consideration.
- **Material non-linearity** – the efforts and strain have plastic distribution, also plastic hinges can be inputted
- **Local non-linearity** where certain

elements are design to have a special stiffness matrix. Good examples can be tensors, which are design to take only tension, or relaxation of cables, which can be model with a gap. Cables also require special FEM elements that take in account the changes in geometry in order to develop only pure tension.

Types of local non-linearity Table 1



3.3. Interpretation of results

After running any of the described above methods results obtain results which are reaction, nodal displacements, tensions, strains, efforts on 1D/2D elements.

With these results the traditional structural engineer has to peak up the combinations for each element and run his own design sheet to do the checks specific for each material with regard to the current design codes.

This traditional approach where the designer programs his own calculation forms in Excel/Mathcad/MatLab has the advantage that the designer has to have a good comprehension of the design code and will always know where the input data has to be placed.

However, there is a major drawback to this method which is the required time and the large grouping of elements.

The designer has to do grouping according to mean efforts and has to choose a few sections on the mean element and check with a number of combination.

The alternative is using the design software full capability. This means using the implemented checks according to code for all elements and then takes some design decision based on unity checks diagram instead of analysing effort diagrams. An example for this approach is the optimization of a steel hall beam.

In this situation we can select a profile for the span area and the for the beam endings we can choose a hunch based on the moment diagram. We can optimise to be close to a unity check and we know all the sectional and stability maximum unity check at a glance.

The drawback of this method is the fact that the user has to have a good comprehension of the design codes and also has to have professional training in using the software. Otherwise the output dimensions are as correct as his input data.

Another aspect might be the fact that the software producer may have his own priorities into developing checks for every country and we may not find a certain check implemented yet.

To solve this problem Scia Engineer adopted a strategy called Open Design. Basically the developed a software called Scia Design Forms which gives the engineer full programing power with all needed tools and without special programing skills. Also they bring databases of materials, bolts, user interface and most important direct integration with the FEM Analysis software.

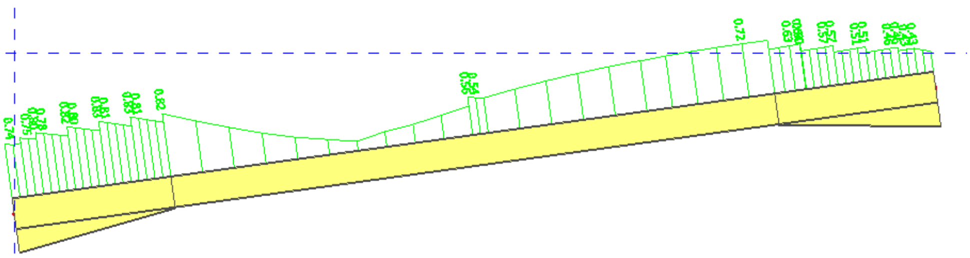


Fig. 9. *Unity check for a hunched beam according to SR EN 1993-1*

So the user can program a check that he can find in a scientific study and obtain a graphical representation of unity checks.

This custom check can also be available in the final engineering report, and is automatically updated should changes occur in the model.

3.4. Structure optimization

There are 3 levels of optimization: [3]

I) Cross-section optimization of element

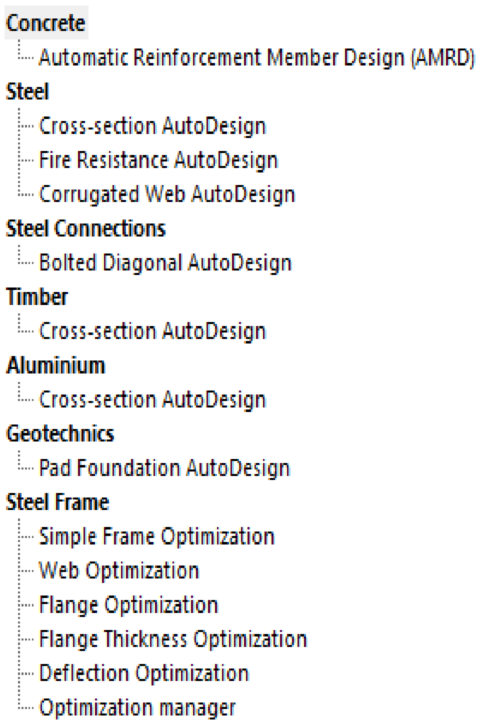


Fig.9. *Cross-section optimization according to material type*

II) Global Optimisation

III) **Engineering Optimization**

Template: Advanced Parametric Optimization

The basic level optimization is the cross-section optimization.

The second level of optimization can be applied to a group of elements (columns, beams, bracings) and becomes very useful when working with static undetermined structures where changing a member affects the moment distribution.

The second level of optimization can use all the available tools displayed for the first level optimization.

The third level of optimization implies using parameter that can define numerous attributes: it can define node geometry, force values, stiffness values, load position points and basically and information that is usually manually inputted can be replaced with parameters.

These parameters can be independent or dependent through user defined formulas.

The user can define the variation range and the step of increment and the software will generate through its genetic algorithms random values that will converge on the solution. As result the software can modify the shape of a structure in order to minimise mass.

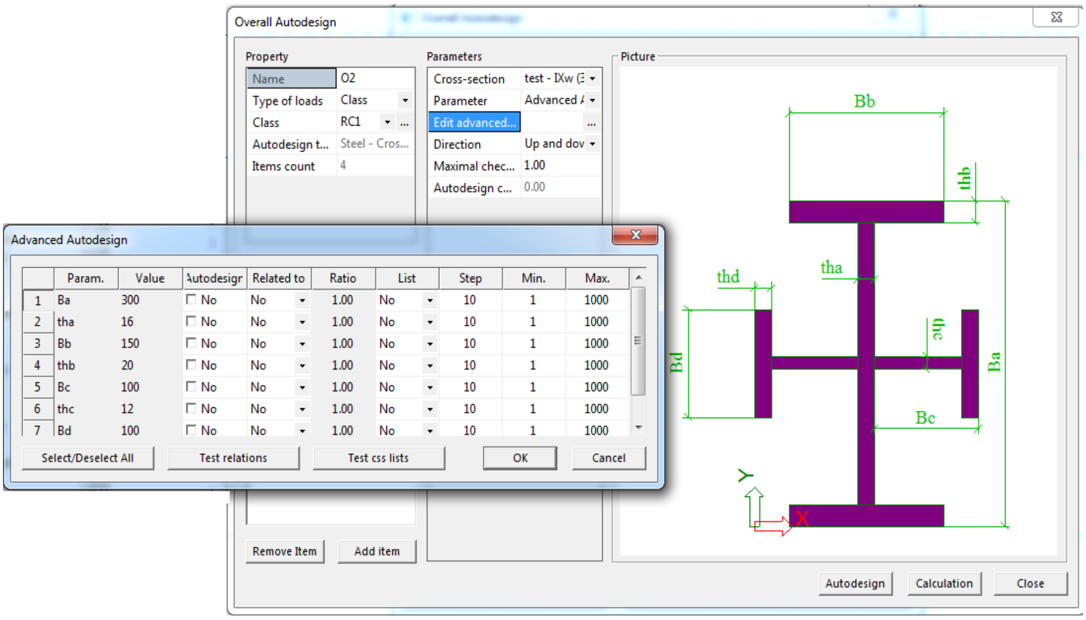


Fig.10. *Advanced auto design, where a group elements can be optimised according to slenderness ratios inputted by the user.*

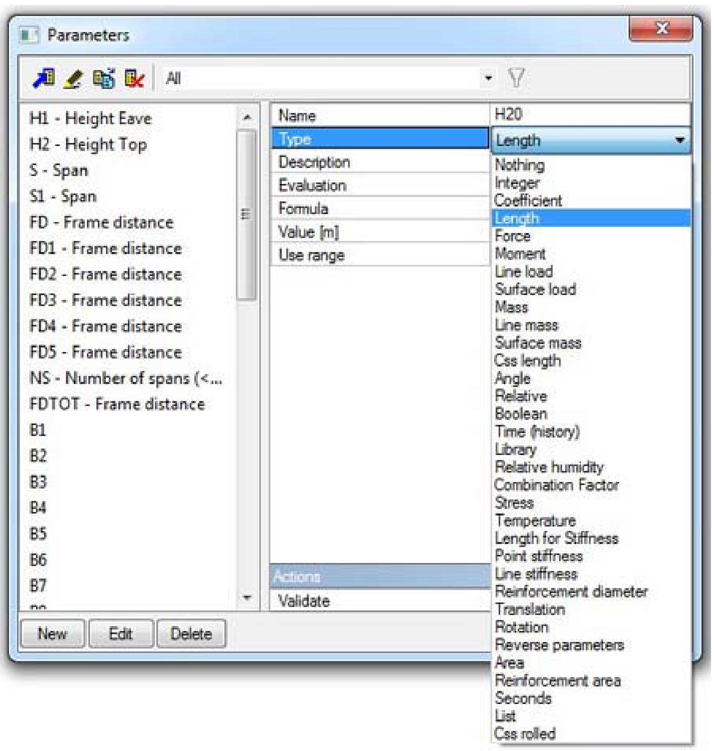


Fig.11. *Defining a model's parameters*

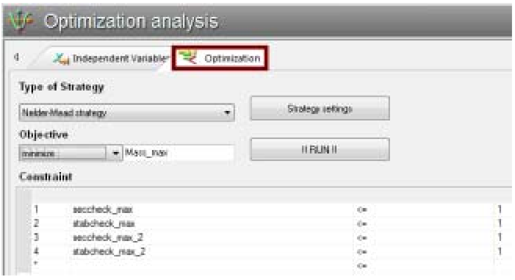


Fig.12. *Defining a value generation strategy, an objective and additional restrictions.*

4. Conclusion

In conclusion, the developments in technology have to embrace with caution. Software will never be able to replace an engineer and the engineer has to see the software as only a tool that saves him time. The results are highly dependent on user input, and the user is the only one responsible for his own project.

However, if there is enough responsibility and experience along with proper training, these modern techniques can be applied with great success.

Acknowledgments

Pictures from chapter 2 are taken from Nemetschek Internal Manual entitled: "BIM made by Allplan".

All pictures in chapter 3 are screenshots from Scia Engineer software.

References

1. C., E. (1999). Eastman C. *Building Product Models: Computer Environments Supporting Design and Construction*. Boca Raton: CRC Press. P. 1-2.
2. *Nemetschek manual*: BIM made by Allplan
3. Popa C., *Advanced parametric optimization AICPS* Review, Romania, May 2014, p.150-158.