Ideas for the rapid development of the structural models in mechanical engineering

E Oanta¹, A Raicu² and C Panait³
¹,²,³Constanta Maritime University, Faculty of Naval Electro-Mechanics, 104 Mircea cel Batran Street, 900663, Constanta, Romania

E-mail: eoanta@yahoo.com

Abstract. Conceiving computer based instruments is a long run concern of the authors. Some of the original solutions are: optimal processing of the large matrices, interfaces between the programming languages, approximation theory using spline functions, numerical programming increased accuracy based on the extended arbitrary precision libraries. For the rapid development of the models we identified the following directions: atomization, ‘librarization’, parameterization, automatization and integration. Each of these directions has some particular aspects if we approach mechanical design problems or software development. Atomization means a thorough top-down decomposition analysis which offers an insight regarding the basic features of the phenomenon. Creation of libraries of reusable mechanical parts and libraries of programs (data types, functions) save time, cost and effort when a new model must be conceived. Parameterization leads to flexible definition of the mechanical parts, the values of the parameters being changed either using a dimensioning program or in accord to other parts belonging to the same assembly. The resulting templates may be also included in libraries. Original software applications are useful for the model’s input data generation, to input the data into CAD/FEA commercial applications and for the data integration of the various types of studies included in the same project.

1. Introduction
Nowadays structural studies extensively use the computers for theoretical models and experimental studies, [1, 2]. Most of the programs used either for the development of the theoretical models, i.e. analytical or numerical models, or for experimental studies, are commercial software applications. In many cases the theoretical models used in research problems must be either refined or redesigned, in order to offer more accurate results, by taking into account new constraints or new assumptions. For all these models the general problem to be solved is to conceive a set of approaches which are applied right from the initial conceptual stage in order to create flexible models which may be easily modified. The reusability of the models is a target that requires a more profound analysis of the research problem and, in several cases, more time for the development of the solutions if software libraries are not already created.

2. Original basic solutions already considered
Rapid development of the structural models in engineering is a long run concern of the authors. A first step was to conceive and develop the ‘building blocks’ of this approach, this means the software
instruments necessary to solve in a flexible way some mathematical problems using analytical, numerical or algorithmic approaches.

In numerical approaches the fine discretization of the domain offers a high accuracy and leads to large amount of data usually expressed as matrices. This is why an early direction of research was the development of data processing techniques for large matrices stored either in random access files, or in arrays of circular doubly linked lists of lines or columns (dynamic memory allocation), [3]. This library was developed in Pascal and it also includes modules that interface the matrices stored in text files to various other programming languages, such as AutoLISP, C++, Java, MATLAB and others, in this way being possible to develop data processors made of several applications written in distinct programming languages. The library was extensively used for the development of various original software instruments in finite element method applications, experimental mechanics, computational fluid dynamics based on the finite difference method, applied physics and economics. At present we study the possibility to define a general dynamic data type which may include any basic data type, to be used as a circular doubly linked list, in this way being targeted a higher level of generality and an easier and faster way to develop numerical programming applications.

The accuracy being an important goal, one of the directions of our studies was dedicated to the accurate approximation of the curves which are either domain boundaries or diagrams of various technical parameters, [4]. The result of this study was a data processor which considers as input data a set of points defined by their coordinates, the output data consisting of the coefficients of the spline functions that approximate each interval of the initial curve. These coefficients are expressed either as data stored in text files using the comma separated value format, or as libraries of automatically generated computer code in C++, Java and GNU Octave. The aforementioned data processor was very useful for several subsequent studies.

Other direction of our studies was the enhancement of the accuracy using libraries that provide customized extended arbitrary precision data types, [5]. In this way we may use a large number of terms when a phenomenon may be mathematically modelled using power series.

A latest direction of development is to customize the program modules already developed in order to create C++ header files that allow us to conceive a library of functions to be used for the rapid development of various software applications. The first header to be used includes user defined data types, therefore changing the type of the variables in the upper level software may be simply done by modifying the data type in this header file.

These basic software instruments were employed for the development of some upper level applications for data processing in mechanical engineering, for data visualization and for CAG/CAD. However, there are specific ideas for the rapid development of the structural models in mechanical engineering.

3. Objectives regarding the rapid development of the structural models
The basic idea is to analyse right from the beginning the most general concepts which are helpful for a general definition of the problem and the methods to divide the initial problem in several smaller and simpler problems. Moreover, if the subsequent smaller problems may be solved using other solutions, such as the direct calculus method, the most simple and accurate methods should be chosen.

A well posed structural problem, i.e. a model, must deal with the following sub-models: the model of the geometry, the model of the supports, the model of the loads and the model of the material. All the data related to these sub-models must be quickly defined and inserted into the theoretical model which is either analytical, or numerical.

The approaches used to create a flexible model must be based on the facilities offered by the nowadays commercial software applications, in this way being interesting the import and export data formats and the possibility to create macros or to automatically process the data.

According to the principle ‘the fewer times the operator is touching the keyboard, the fewer mistakes may occur’, the approaches to solve a problem should use automatic computing generated data.
Last but not least, the solutions to be developed must be general, flexible and reusable in other projects.

4. Discussion
There are several ideas to create a strategy regarding the rapid development of the models in accord with the previously mentioned requirements.

In broad lines, the general directions to be followed are: atomization, ‘librarization’, parameterization, automatization and integration, each of these directions having some subsequent options.

Atomization is a direction suggested by the relational databases theory and practice where the large collection of information is gradually separated in data that cannot be furthermore divided and a catalogue of atomized information may be expressed as database tables. In our case the structural analyst must identify all the common aspects and functionalities by evaluating the phenomenon from an abstract level and from several points of view. In this way there may be conceived the most appropriate reference (type and position of the system of axes, relative level of the loads, basic features of the supports influences), the basic sets of information, together with a basic set of operations, such as: identic to, (progressive) addition/subtraction, multiplication, mirroring, replication and others. This top-down decomposition analysis is paramount in the breaking down of the phenomenon under investigation in order to gain insight into its basic features, using a reverse engineering approach. Once this stage is completed, the structural analyst has a hierarchy of basic features and basic functionalities to be used in the following analyses and developments. A tree diagram of the basic information is useful to clarify the results of this analysis.

Creating libraries of reusable information is an intelligent way to save time, cost and effort when a new model must be conceived. In this way, the ‘librarization’ may be used in several fields. In CAD we use libraries of standard parts, components, groups of parts and others. Recognizing the importance of the concept of ‘reusability’, Siemens NX offers the “NX Re-Use Library” solution, together with a standard parts library, i.e. “machinery library with an extensive collection of ready-to-use parts, such as screws, washers, nuts, bearings, pins and other components”. If computer programming is used in the development of a model, libraries of data types and functions allow the analyst to quickly develop the necessary software instruments, this aspect being included in the ‘automatization’ direction.

![Figure 1. Parametric design in NX exported to Femap/Nastran.](image)

Using parameterization, some of the dimensions of a mechanical part are given as numbers, being designated parameters of the model and other dimensions are defined with respect to the parameters previously set. In this way, by changing the values of the parameters, the entire model is modified. Moreover, the appropriate values of the parameters may be computed using a program. In this way there may be created a library of templates, which may be related one to the other and assembled when a new design is required. In the previous figure is presented a parametric design of a weighting device developed in NX which was exported to Femap/Nastran in order to analyse the stresses and the displacements using the finite element method, [6].
Automatization is based on the development of computer code to be used for various purposes in modelling. A first goal is the computer based analytical modelling of the structural phenomenon. The resulting data may be used either to create a computer based genuine analytical model, or to create a numerical model using a commercial software.

**Figure 2.** General loop related to a structural model which may be used for various studies.

The results of the theoretical model consist of stresses and displacements, and they must be under the values of the allowable stress or of the allowable displacement. Once this condition is verified, the verification unit of the model may be included in an upper level loop where the input data consisting of geometric dimensions are modified until the conditions of the previously mentioned verifications are satisfied, in this way being done the dimensioning of the structure. Using the same procedure for a certain set of dimensions and modifying the values of the loads, there may be computed the maximum load supported by the structure. Other application of this algorithm is to compute the accuracy of the theoretical models’ results vs. the results of the experimental studies.

**Figure 3.** Visualisation based on script files in AutoCAD.

The data generators may be also used to create the geometry of the model in CAD commercial software, using the according facilities. In NX the parameters may be stored in an Excel table where the values are read from a comma separated value file created by the data generator. In AutoCAD there may be used script files where the commands are written by the data generator, in this way the visualisation of the structure being automatically done, figure 3, [7]. Once the geometry is created in the CAD application, it may be exported to a finite element method based analysis software.
The data outputted by the data generators may be imported in a software application in order to perform the analysis. In the following figure is presented a library developed in Visual Basic which used the API facilities offered by Femap/Nastran. In this case the pre-processed data are stored in text files using the comma-separated-value format, [8].

![Library Developed in Visual Basic](image)

**Figure 4.** Functions included in the ‘Utilities.BAS’ library. The ‘Load_CSV’ function reads a CSV file and outputs a matrix which contains the according data.

The data stored in a CSV format may be used for the automatic generation of the geometry and of the loads, figure 5, [9].

The software instruments presented so far are useful for the automatic data generation and for the facile input of the data into commercial software or in computer based analytical models. Another goal is the integration of the information between the various types of models of a complex study, figure 6.
Using original software interfaces, the data may be sent between the studies and between the sub-models of a model. In this way, integration means not only a common database of the theoretical models, but a deep integration of all the studies of a model which leads to an upper level of understanding of the phenomenon under investigation and to accurate results of the model.

5. Conclusions
An analyst has a wide range of options when a structural model must be designed. Starting with a relative precise analysis of the problem, the analyst must decide the best ratio ‘man-hour’ vs. ‘accuracy of the results’, according to which a work breakdown structure of the model development may be conceived.

The stages and options useful to conceive a structural model in mechanical engineering identified by us are atomization, ‘librarization’, parameterization, automatization and integration. These stages are also useful for the steady state development of the research software instruments. We already conceived and tested several computer based solutions for data processing, numerical programming, application program interface in Femap/Nastran and for data visualisation.

The examples given in the figures of the paper show the high versatility and flexibility of the computer based solutions considered by us for a rapid development of the structural models in mechanical engineering, solutions which may be used in many complex projects [10, 11, 12].

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