

## SOFTWARE PACKAGE FOR EXPERIMENTAL DATA PROCESSING

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### **Abstract:**

*Most scientific research uses experiments to confirm theoretical approaches or to understand different phenomena. These experiments can be very simple or more complex. The complexity of the experiment influences the precision of the results, the duration of the experiment and the labour or material cost. The most accurate and expensive experiment is the classical one, where a total of 5 tests are conducted at every key point of the experiment. If a lower accuracy (i.e. 95%) is acceptable, there are also less expensive experiments which can be made, also called active experiments. Because active experiments require fewer tests, they must be designed accordingly. This article presents a software package for the planning of classical and active experiments and for processing the obtained experimental data.*

**Key words:** *passive and active experiments; design of experiments; experimental data processing.*

## INTRODUCTION

The importance of experimental research is well-established in the scientific world. Experiment accuracy is very important. But research costs must also be considered. In order to achieve accurate results, experiments are often complex, thus requiring a lot of time and higher labour and material costs. Therefore, researchers must establish which experiments should produce higher precision results and which can also lead to less accurate results. In high precision experiments, a total of 5 tests are usually conducted at the key points of the experiment. These experiments are called passive or classical experiments and are very costly. Cost reduction is possible with active (scheduled) experiments, which are usually less accurate. Relevant specialist literature presents various methods for reducing the number of tests, like preliminary experiments, complete factorial and central experiments. With these types of experiments, a result accuracy of up to 95% can be achieved.

## OBJECTIVES

Because active experiments require special planning beforehand and extensive data processing afterwards, this software package was developed to help researchers during the experimental process.

## METHOD, MATERIALS AND EQUIPMENT

Reducing the number of tests of a classic experiment can be done in two ways:

- establishing the factors that have a significant influence on the process by employing preliminary experiments (random balance method, mono and multi factorial dispersion analysis)
- using active Complete Factorial Experiments (C.F.E) and Central Composed Experiments (CCE).

### Preliminary experiments

Before an experiment is conducted, the factors which shall be taken into account must be established (Taloi 1987). The higher the number of these factors, the greater the number of necessary tests. It is possible that not all the factors will have a significant influence on the studied phenomena. Therefore, it is advisable to carry out preliminary experiments to establish which factors do have a significant influence, thus eliminating the less relevant factors and reducing the number of necessary tests. In specialist literature we can find several methods to determine the influence of individual factors, like the Random Balance Method, the Dispersion Analysis Method, the Correlation Coefficients Method etc.

In the Random Balance Method (Fig. 5, 11), two levels are established for each factor: a minimum level (labeled -1) and a maximum level (labeled +1). These levels are established after one test. For higher precision, two to five tests can be conducted. After completing the experimental plan, the values of the dependent variable  $y$  are divided into two groups for each studied factor: one that encompasses all the minimum values of  $y$  and one that includes all the maximum values. For each group, the median is calculated (middle value in values), then the two medians are subtracted from each other. The higher the difference, the stronger the influence of the factor.

The Dispersion Analysis is performed for one factor (mono factorial dispersion analysis) (Fig. 6a, 12a) or for two or more factors (multi factorial dispersion analysis) (Fig. 6b, 12b). For the mono factorial analysis, only one factor is changed to  $m$  levels and the other factors are maintained constant. For the multi factorial analysis, two or more factors are changed to  $m$  levels and the other factors are maintained constant. For each level, a number  $n$  of parallel tests are performed.

The significance of a factor is determined by computing the ratio of the deviation caused by this factor and the deviation of the variable  $y$ . The degree of truthfulness of the studied influence factor is determined using the Fisher criterion.

### Proper experiments

After eliminating the factors with a less significant influence on the process, we can start with the proper experiment, which can be classical or active (Taloi 1987, Kiesling, Wikipedia - Design of experiments).

▪ **Classical experiments** are the best known and used in experimental research. Fig. 1 and Fig. 7 show experimental plans for classical experiments with one, two, and three factors ( $x_1$ ,  $x_2$  and  $x_3$ ). If at every point of the experiment 5 tests are conducted, 25 tests are required for one factor ( $5 * 5$  data points), 125 tests for 2 factors ( $5 * 5 * 5$  data points) and 625 tests for three factors ( $5 * 5 * 5$  data points).

▪ **Active experiments** work with fewer tests, but results are 5-10% less accurate. When the accuracy of the experiment is not as important and it is intended only to establish a linear trend of variable  $y$ , it is possible to use Complete Factorial Experiments C.F.E  $n^k$  (Fig. 2a, 8, 13a), where the values of the influencing factors are established at two values - a minimum (-1) and a maximum (+1) value (Fig. 3, a). An experiment C.F.E  $2^2$  with two factors at two levels requires at least four tests. For greater accuracy, several parallel tests can be performed at every point of the experiment.

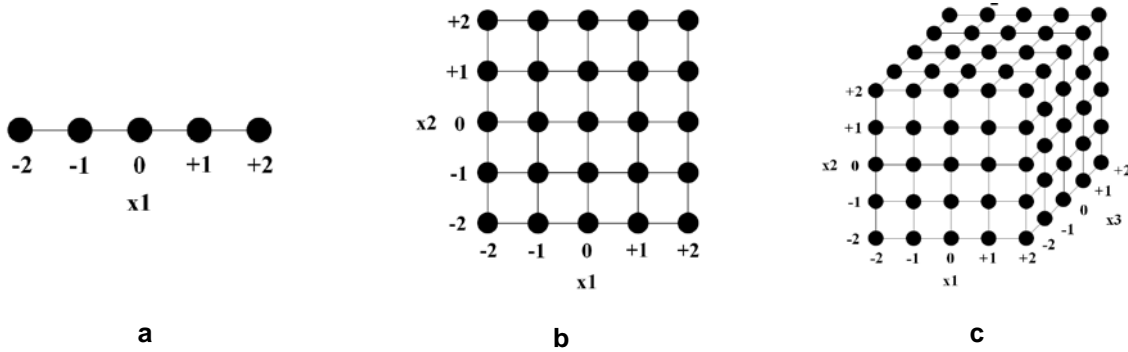


Fig. 1

Experimental plans for passive (classical) experiments.

a – one factor,  $y=f(x_1)$ ; b – two factors,  $y=f(x_1,x_2)$ ; c – three factors,  $y=f(x_1,x_2,x_3)$ .

If we intend to optimise the process by establishing non-linear dependencies for the variables, it is recommended to use Central Composed Experiments, like Orthogonal Experiments C.C.O.E (Fig. 2b, 13b) or Rotated Experiments C.C.R.E (Fig. 2c, 9, 14). In the case of orthogonal experiments, for two factors the factorial plan of C.F.E  $2^2$  (4 tests) is completed with 5 tests in the centre of the experiment (0,0) and one test in the points noted with  $-\alpha$  and  $+\alpha$  (for 2 factors  $\alpha = 1$ , for 3 factors  $\alpha = 1.215$ , for 4 factors  $\alpha = 1.414$ ). Two factors require 13 tests. The rotated experiments are similar to the orthogonal experiments, except for varying values for  $\pm \alpha$ : for 2 factors  $\alpha = 1.414$ , for 3 factors  $\alpha = 1.682$  and for 4 factors  $\alpha = 2$  etc. In order to increase the reliability of the obtained results, instead of one test / point it is possible to conduct multiple tests in parallel.

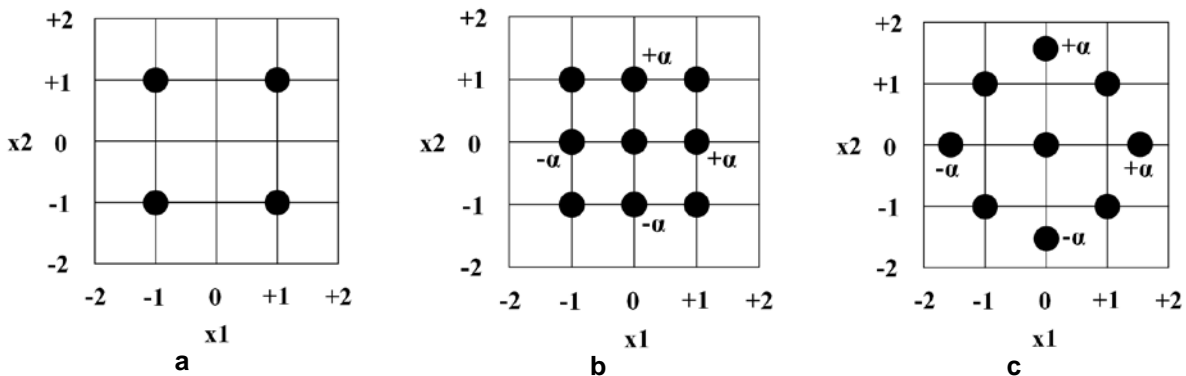


Fig. 2

Experimental plans for active experiments with two factors  $y=f(x_1,x_2)$ .

a – C.F.E  $n^k$ ; b – C.C.O.E; c – C.C.R.E

### Software package

Based on these methods, the program presented in this paper was developed (Laurenzi 2009). The program has three major modules: a module for programming experiments, a module for data acquisition and a module for processing experimental data (Fig. 3).

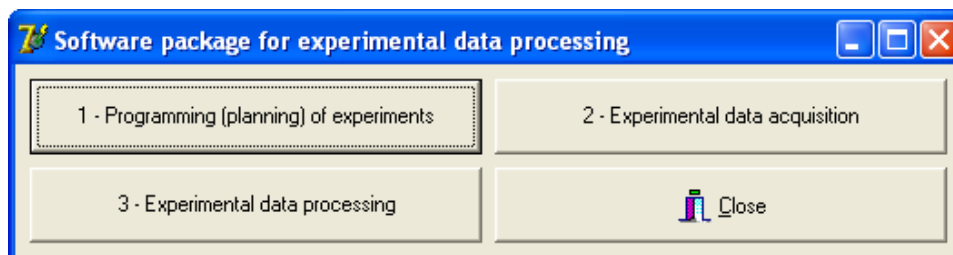


Fig. 3

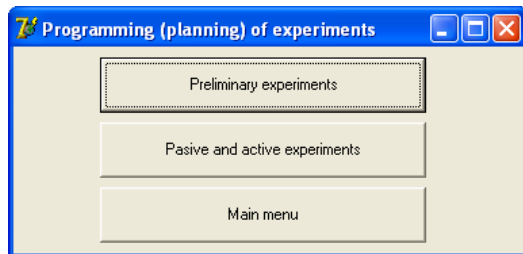
Main menu of the software package.

By pressing the button "1 - Programming (planning) of experiments", the programming menu for preliminary and passive (classical) or active experiments (Fig. 4a) is displayed.

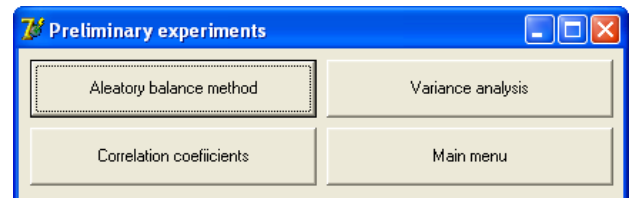
By pressing the button "2 - Experimental data acquisition", the program for calculating the average of the measured values (Fig. 10) is launched.

By pressing the button "3 - Experimental data processing", the program for modelling the experimental data and for simulation and graphic representation of the mathematical models with two or three factors  $y=f(x_1, x_2)$  or  $y=f(x_1, x_2, x_3)$  (Fig. 7 - 9, 13 – 16) is launched:

- with two factors  $y=f(x_1, x_2)$ :
  - linear without interactions:  $y(x_1, x_2) = b_0 + b_1 \cdot x_1 + b_2 \cdot x_2$ ;
  - linear with interactions:  $y(x_1, x_2) = b_0 + b_1 \cdot x_1 + b_2 \cdot x_2 + b_{12} \cdot x_1 \cdot x_2$ ;
  - nonlinear:  $y(x_1, x_2) = b_0 + b_1 \cdot x_1 + b_2 \cdot x_2 + b_{12} \cdot x_1 \cdot x_2 + b_{11} \cdot x_1^2 + b_{22} \cdot x_2^2$
- with three factors  $y=f(x_1, x_2, x_3)$ :
  - linear without interactions:  $y(x_1, x_2, x_3) = b_0 + b_1 \cdot x_1 + b_2 \cdot x_2 + b_3 \cdot x_3$ ;
  - linear with interactions  $y(x_1, x_2, x_3) = b_0 + b_1 \cdot x_1 + b_2 \cdot x_2 + b_3 \cdot x_3 + b_{12} \cdot x_1 \cdot x_2 + b_{13} \cdot x_1 \cdot x_3 + b_{23} \cdot x_2 \cdot x_3$
  - nonlinear:  $y(x_1, x_2, x_3) = b_0 + b_1 \cdot x_1 + b_2 \cdot x_2 + b_3 \cdot x_3 + b_{12} \cdot x_1 \cdot x_2 + b_{12} \cdot x_1^2 \cdot x_2 + b_{23} \cdot x_2^2 \cdot x_3 + b_{11} \cdot x_1^2 \cdot x_1 + b_{22} \cdot x_2^2 \cdot x_2 + b_{33} \cdot x_3^2 \cdot x_3$ ;



a

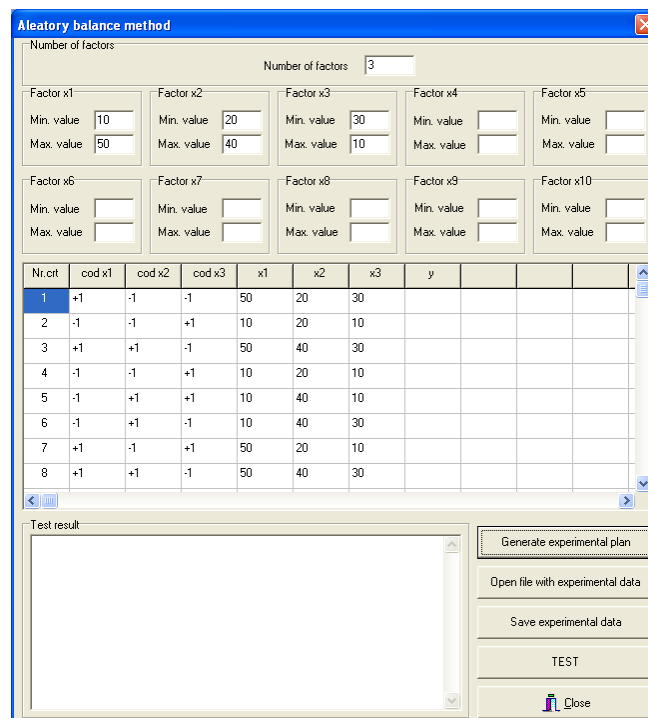


b

**Fig. 4**

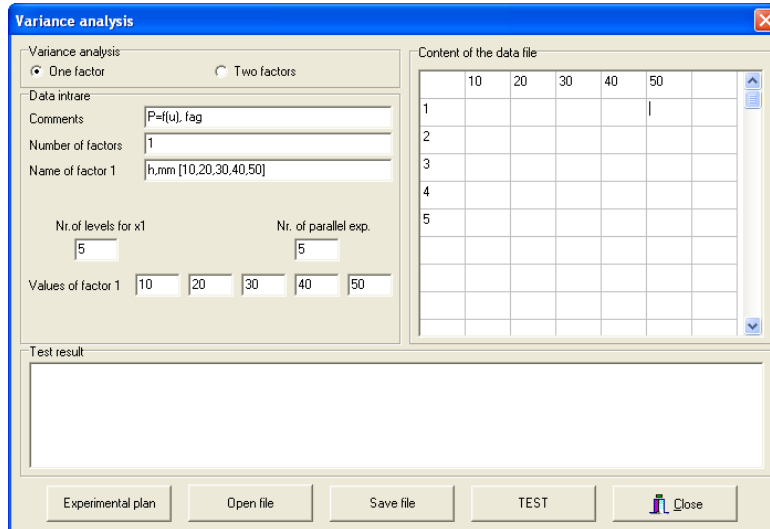
**Other menus of the software package.**

**a - programming (planning) of the experiments; b – preliminary experiments.**



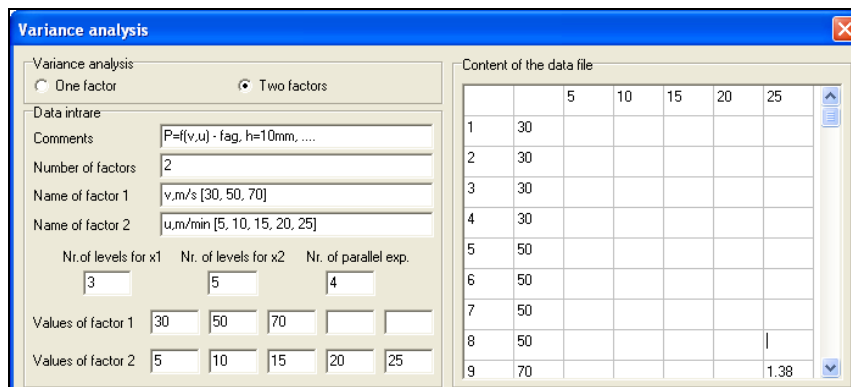
**Fig. 5**

**Experimental plan for the aleatory balance method.**



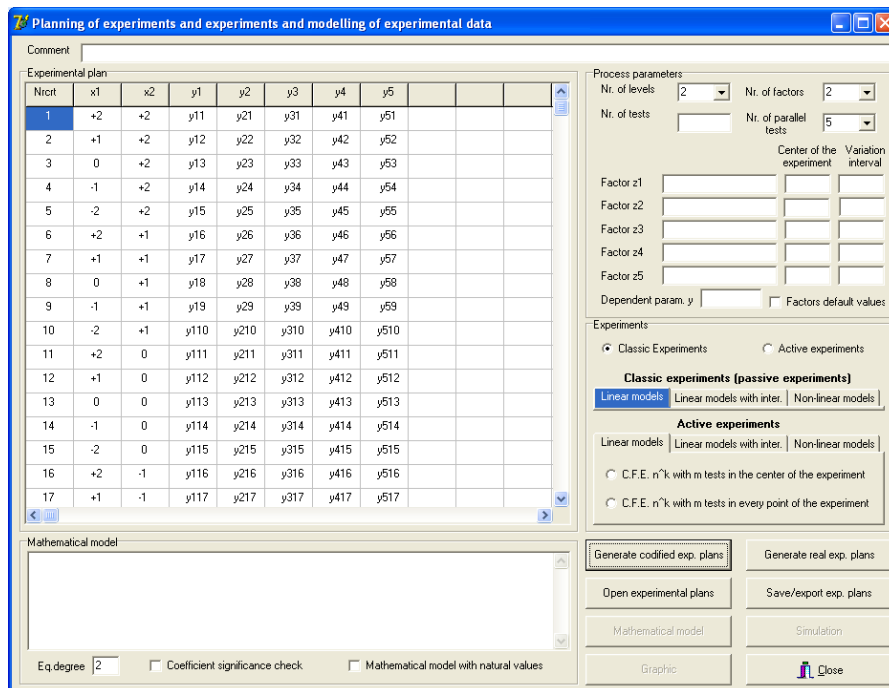
**Fig. 6**

**Experimental plan for the Variance analysis method with a single factor.**



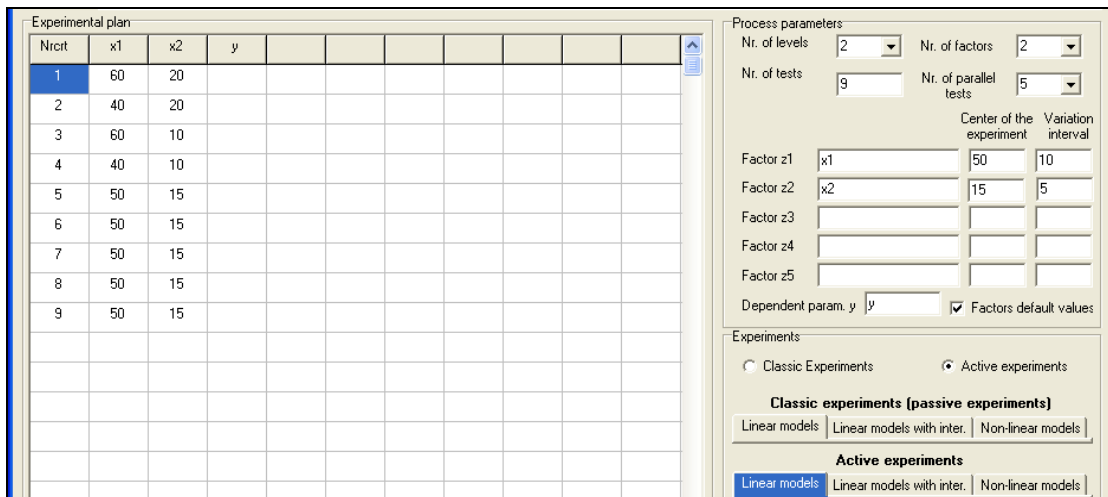
**Fig. 6**

**Experimental plan for the Variance analysis method with two factors.**

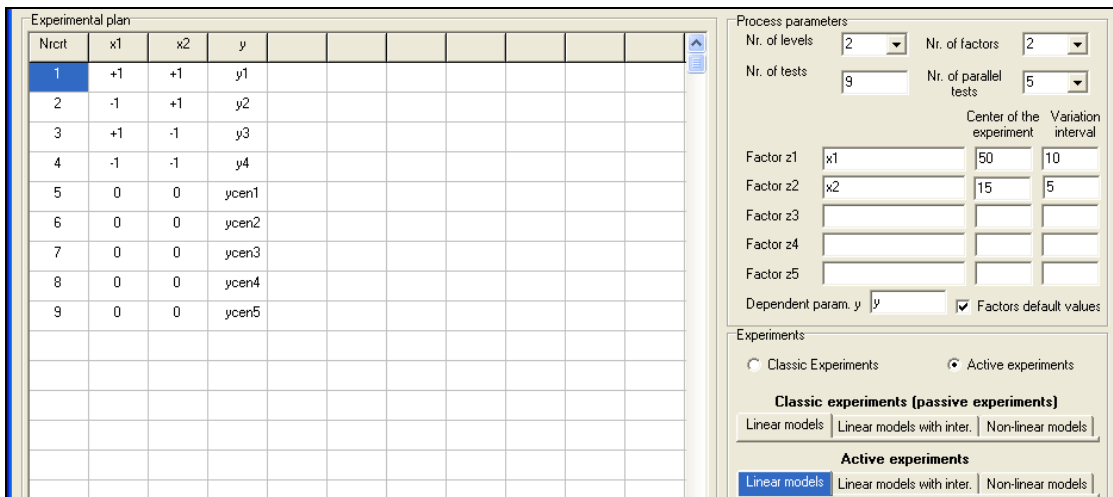


**Fig. 7,a**

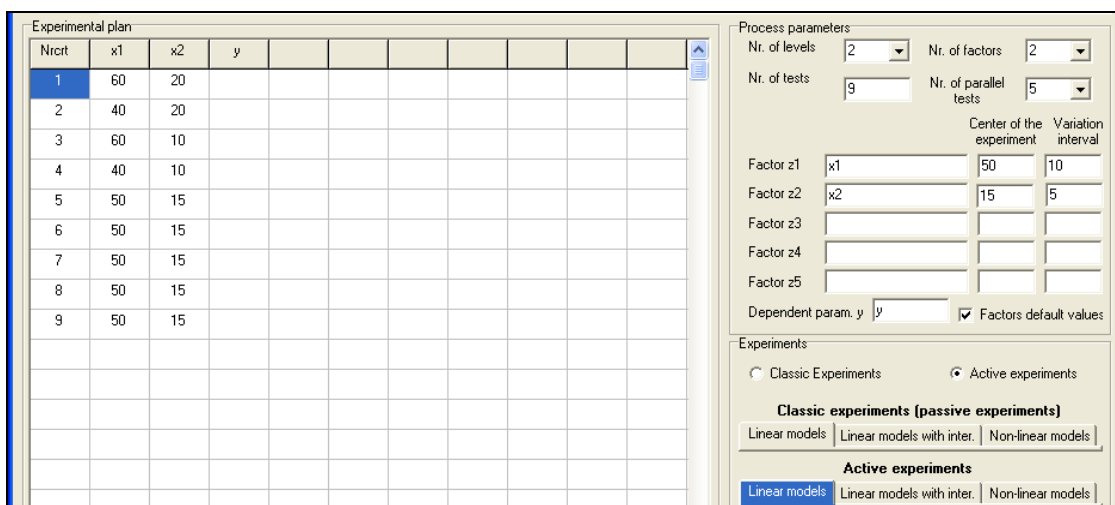
**Experimental plan with codified values (-2, -1, 0, +1,+2) for the passive (classic) experiment.**



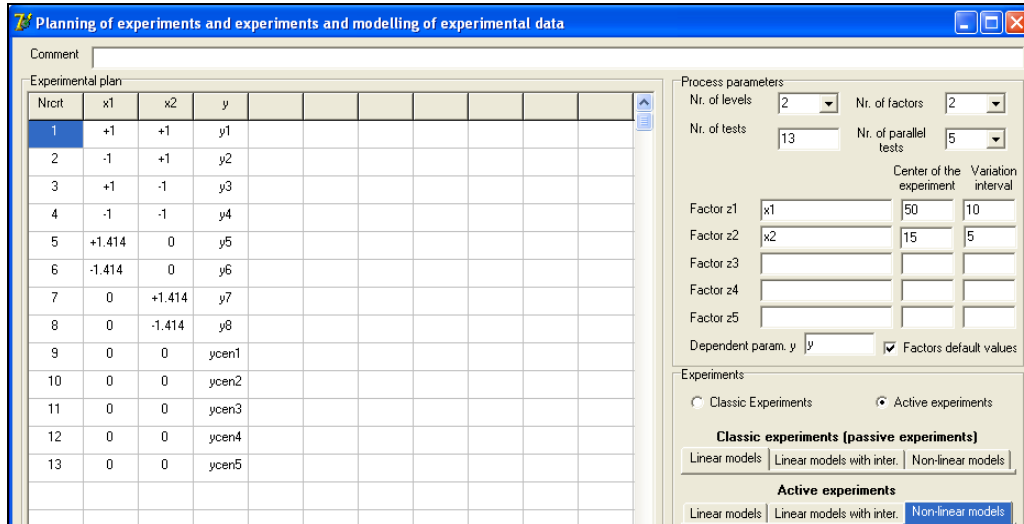
**Fig. 7,b**  
*Experimental plan with real values for the passive (classic) experiment.*



**Fig. 8,a**  
*Experimental plan with codified values for the C.F.E experiment (linear dependencies).*

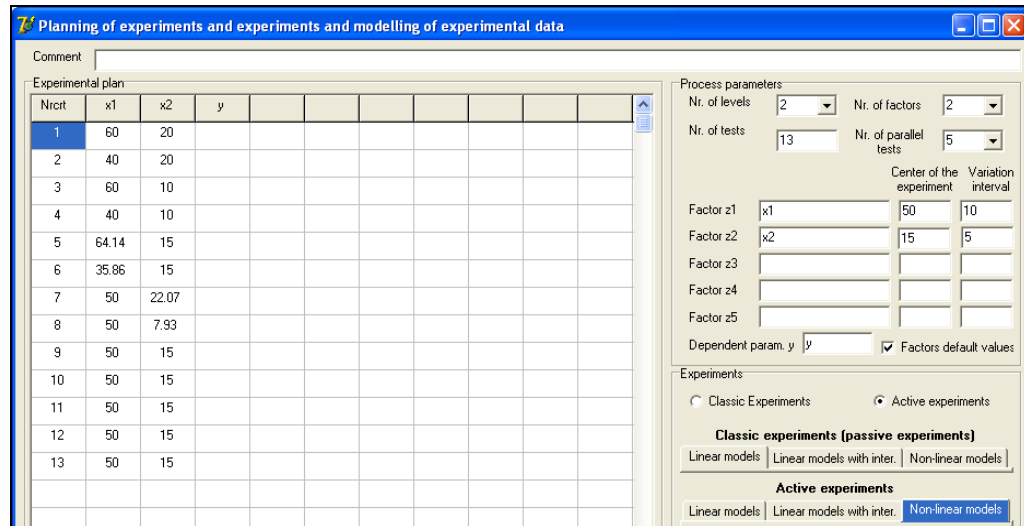


**Fig. 8,b**  
*Experimental plan with real values for the C.F.E experiment (linear dependencies).*



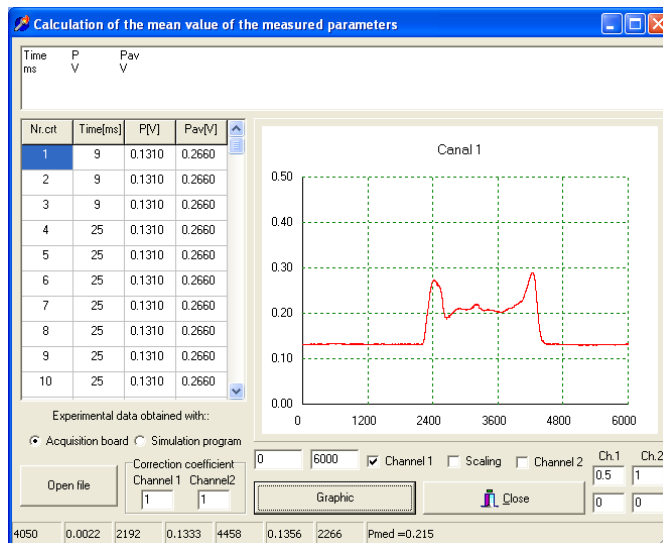
**Fig. 9,a**

**Experimental plan with codified values for the C.C.R.E (non-linear dependencies).**



**Fig. 9,b**

**Experimental plan with real values for the C.C.R.E (non-linear dependencies).**



**Fig. 10,a**

**Menu for calculation of the mean for the measured data (one channel).**

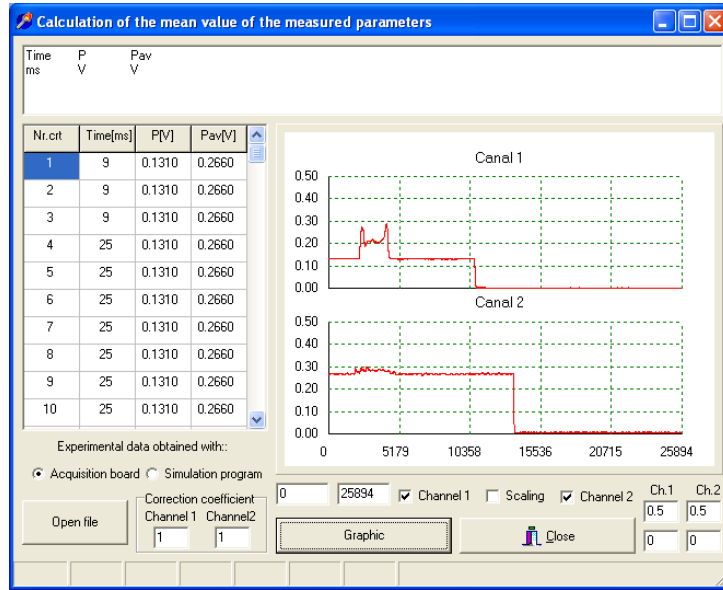


Fig. 10,b

Menu for the calculation of the mean for the measured data (two channels).

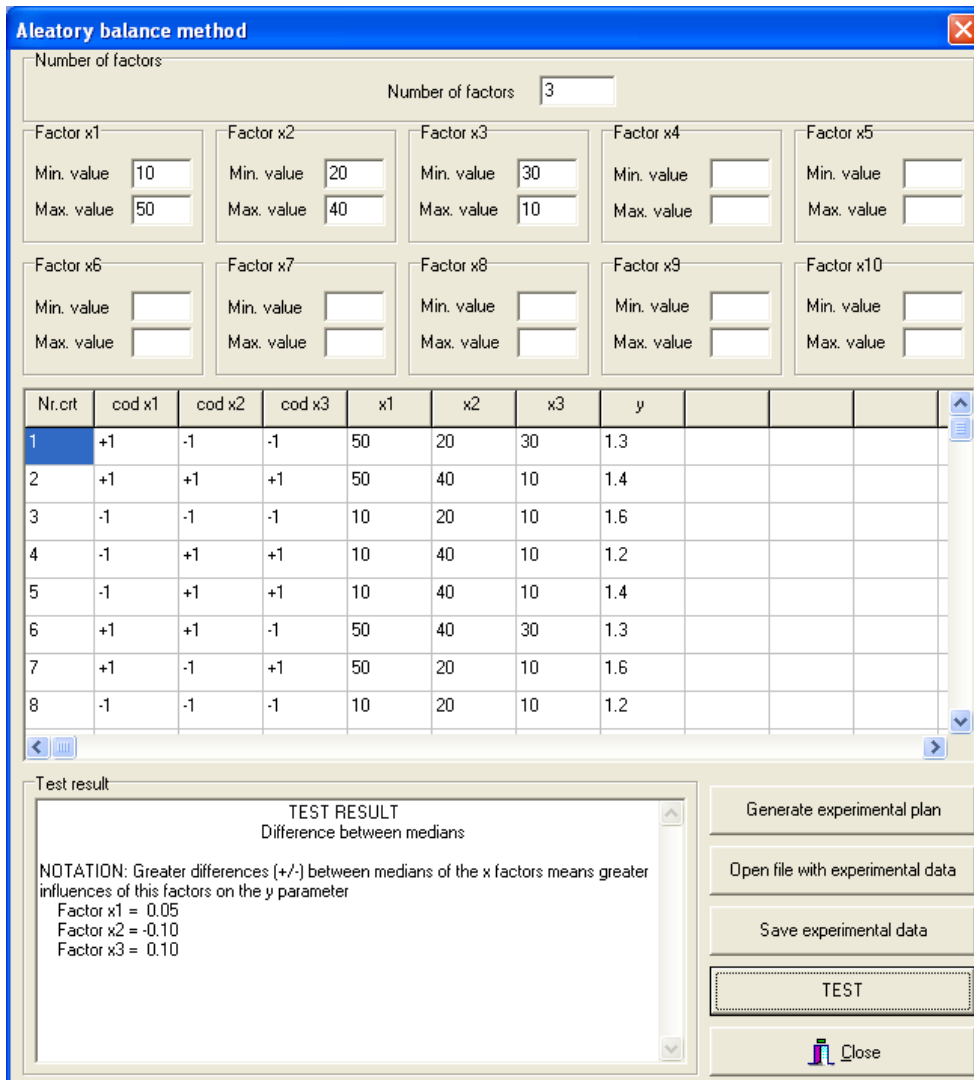
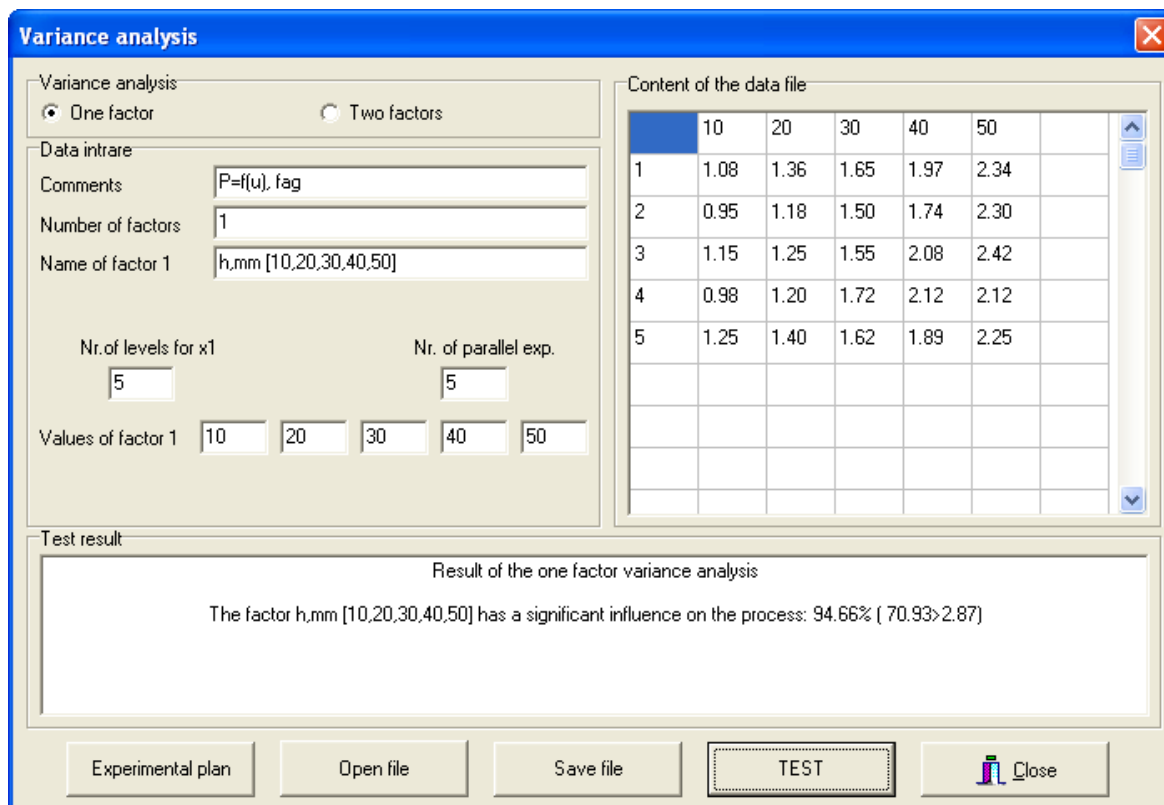


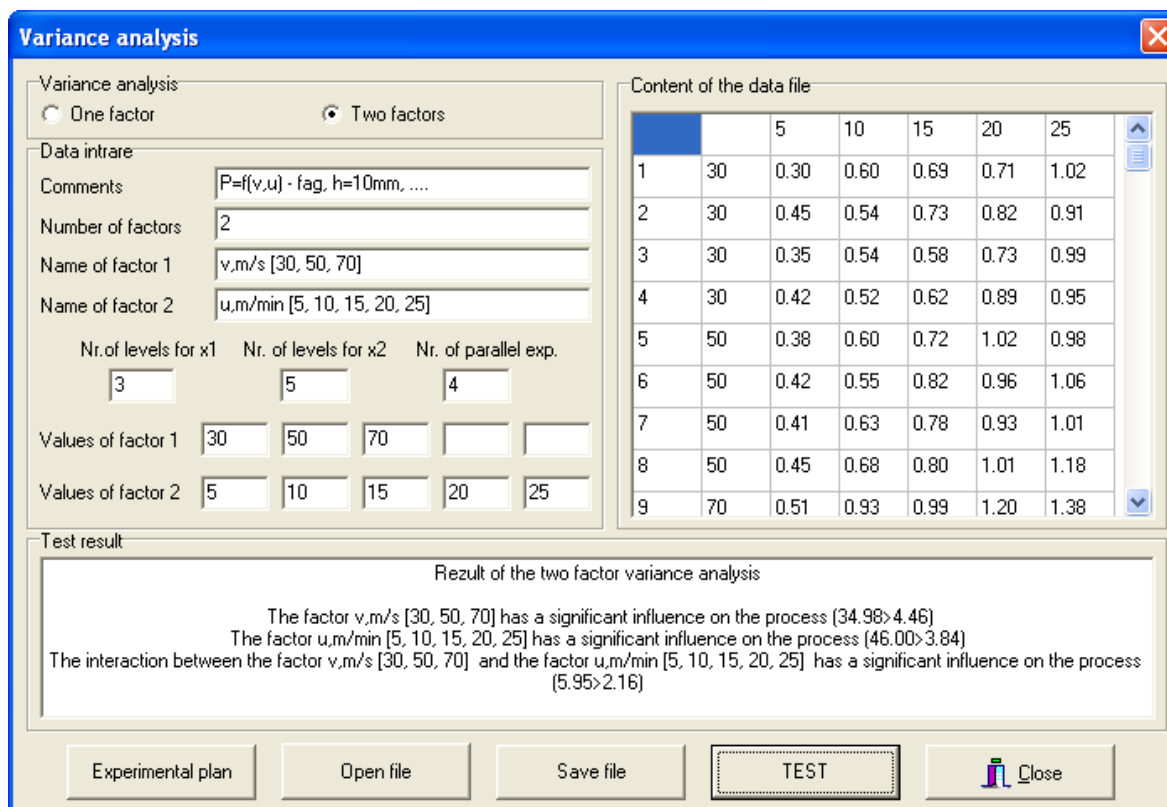
Fig. 11

Experimental plan with measured values and the test result for the Aleatory balance method.

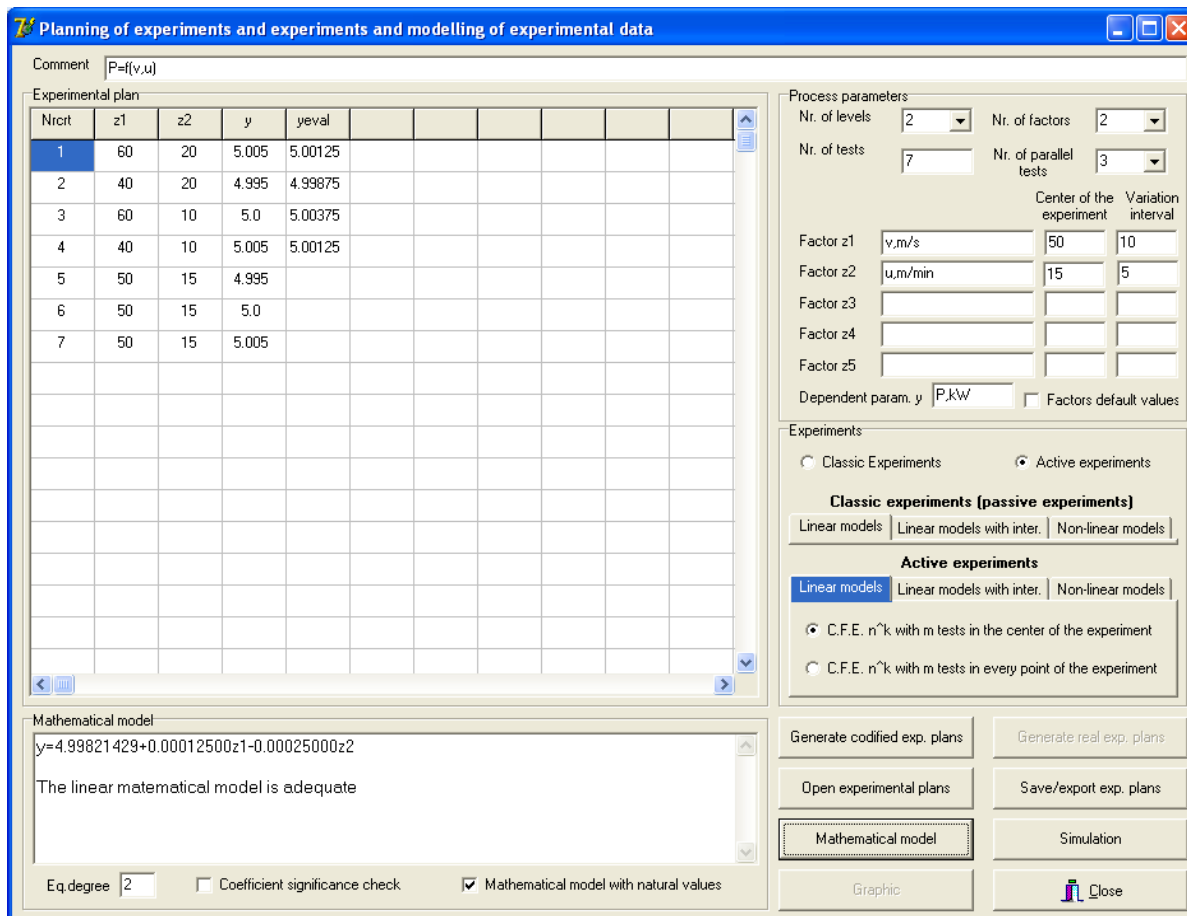




**Fig. 12,a**  
**Experimental plan with measured values and the test result for the mono factorial Variance Analysis method.**

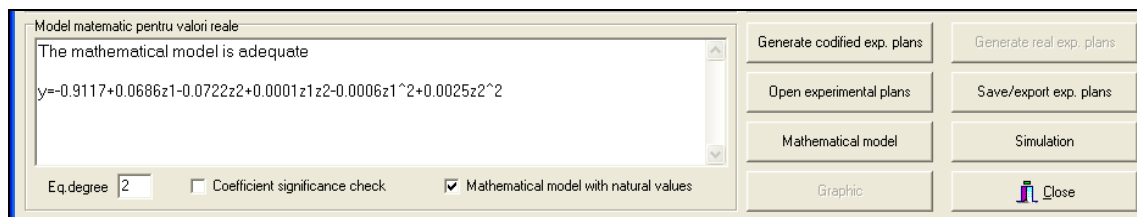


**Fig. 12,b**  
**Experimental plan with measured values and the test result for the multi-factorial (two factors) Variance Analysis method.**

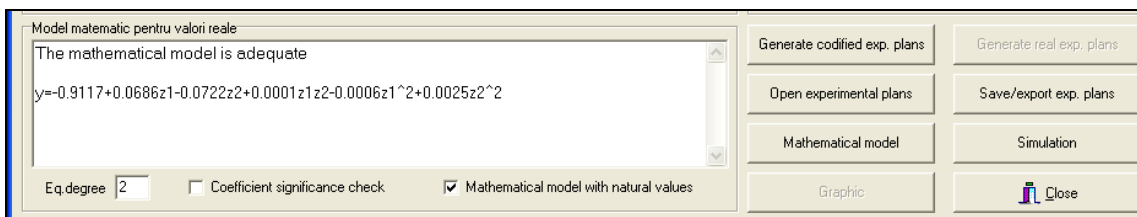


**Fig. 13,a**  
**Experimental plan with measured values and the mathematical model for the C.F.E experiment.**

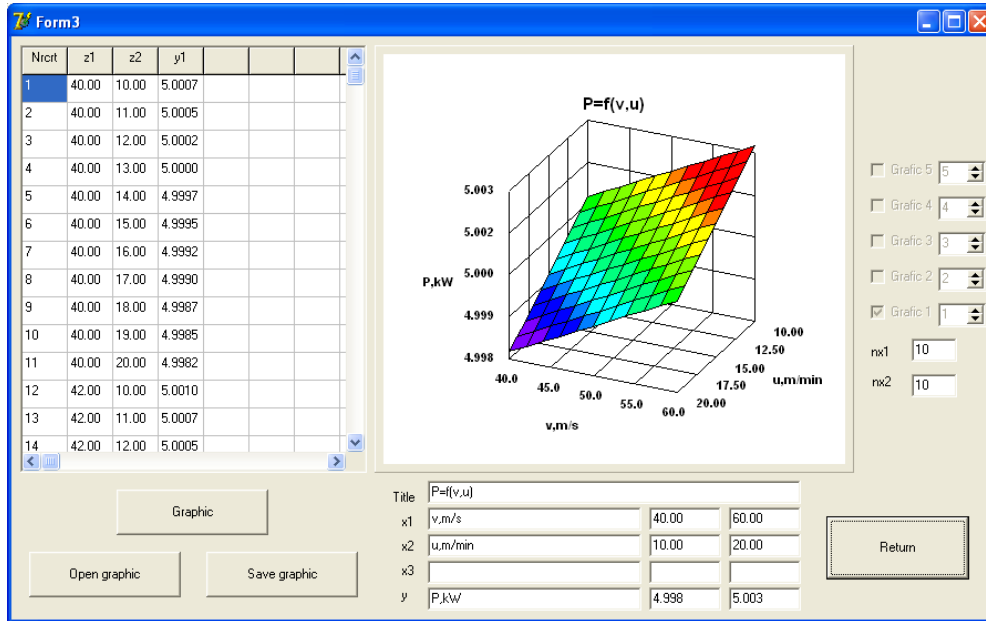
Similar with the experimental plan and the mathematic model presented in Fig. 13,a are the experimental plans for C.C.O.E (Fig.13, b) and C.C.R.E (Fig. 13,c) experiments.



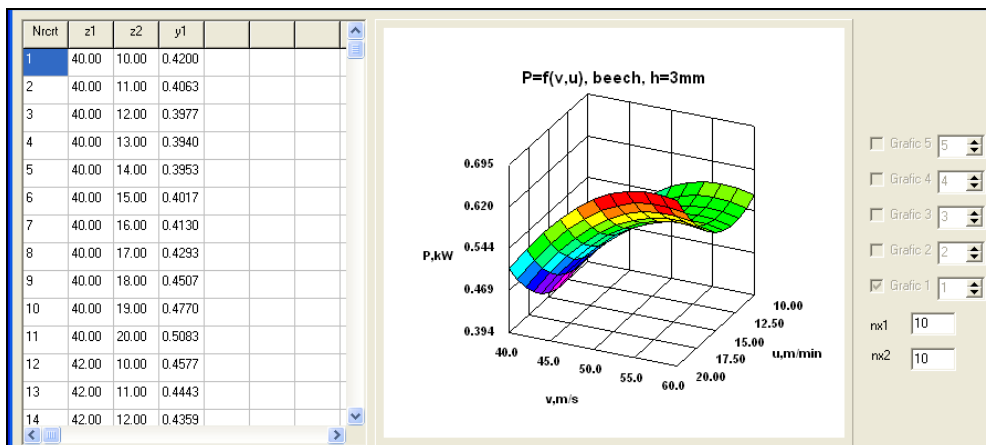
**Fig. 13,b**  
**Experimental plan with measured values and the mathematical model for the C.C.O.E experiment.**



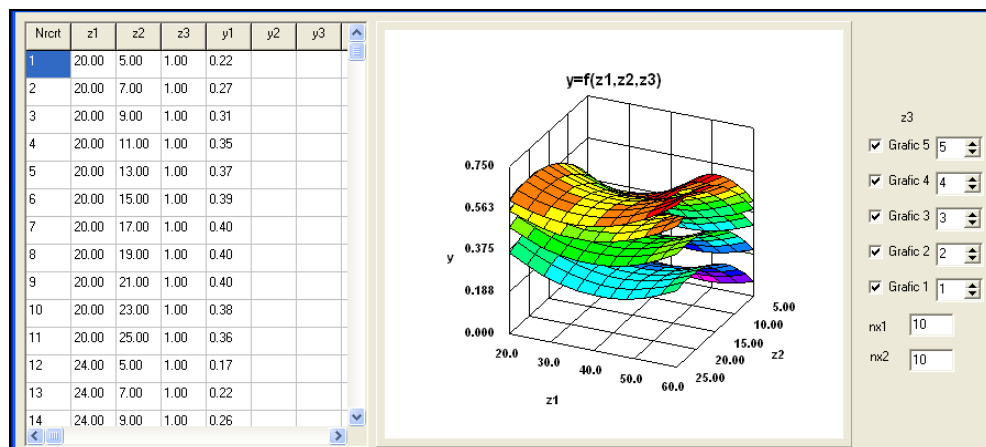
**Fig. 13,c**  
**Experimental plan with measured values and the mathematical model for C.C.R.E experiment.**



**Fig. 14**  
*Menu for graphical presentation of the mathematical model for one factor,  $y=f(z_1)$ .*



**Fig. 15**  
*Menu for graphical presentation of the mathematical model for 2 factors,  $P=f(v,u)$ .*

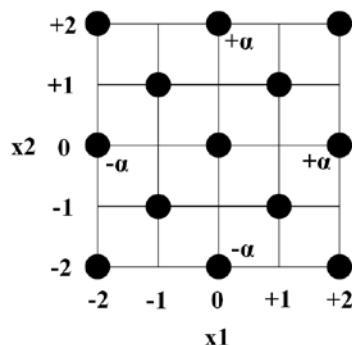


**Fig. 16**  
*Menu for graphical presentation of the mathematical models for 3 factors  $y=f(z_1,z_2,z_3)$ .*

## RESULTS

The software package presented is quite complex and is still in the phase of testing and improvement. On base of few information obtained as a result of experimental researches results that active experimental plans are very good for study of homogeneous materials and applicable with certain reservations for heterogeneous material, such as wood. Taking this conclusion into account, the orthogonal and the rotatable experimental plans could be supplemented with additional points and with more parallel tests in every point of the experiment (Fig. 17). The minimum number of tests would be 17 (5 in the centre point + 12 in the other points) and maximum 65 tests (13 points \* 5 tests in each point). Currently the program does not support planning of these types of experiments.

Before formulating definitive conclusions for different kinds of materials more comparative studies are needed between classical and active experiments. In the same time the software package is continuously improved and tested.



**Fig. 17**

*Experimental plan for heterogeneous materials, 2 factors,  $\alpha=+2$  (proposal).*

## CONCLUSIONS

The software package presented in this article is a useful tool for any researcher working in experimental research. Firstly, it helps with planning preliminary, classical and active experiments. Secondly, it helps with processing the experimental data measured in the process by obtaining linear and non-linear mathematical models. And last but not least, it allows the simulation and graphical representation of these mathematical models in order to help interpret the results of the experimental research.

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