UNIVERSITY OF DERBY

AUTOMATIC DESIGN & CORRECTION OF CERAMIC COLOURS

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Project Tasks:

Develop ceramic glaze recipes which:

- **match** a desired ceramic colour
- **correct/fine tune** a ceramic colour

Outcome: Taguchi's method, Regression & GUI

Work supported by: URSS & Erasmus

Research hosted by:
Universitea 1st Decembrie 1918, Alba Iulia, Romania & IPEC

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IPEC Alba Iulia

- **Leading ceramics producer (1%)**
- **Key supplier for IKEA**
- **Top company for Innovation**
- **CMMRC project: 103.000 Euros**

Challenge:

The company is highly automatized.
Colour design is largely based on trial and error.

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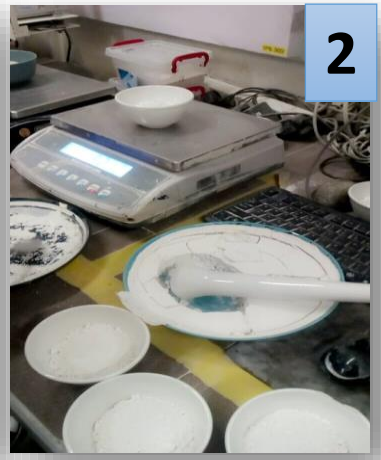
Current Industrial Process

Key steps in making coloured ceramics:

Largely based on skilled human operators:

- Costly
- Time-intensive

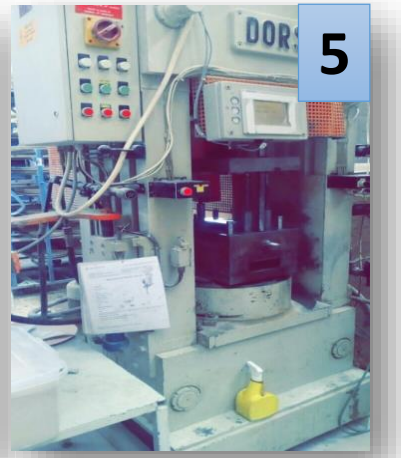
Machine producing the glaze



Weighing machine to weigh glaze and pigments concentration

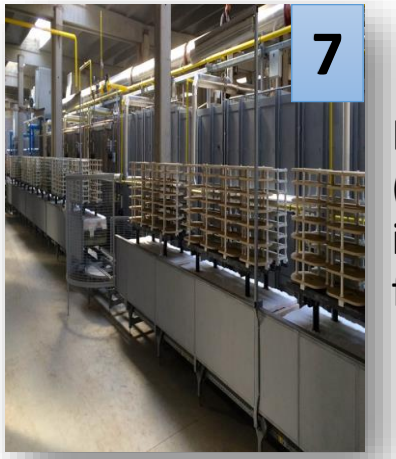
Mixer to mix matte or glossy glaze, pigment & water (various quantities)

Mixtures poured into glasses with different pigment concentrations

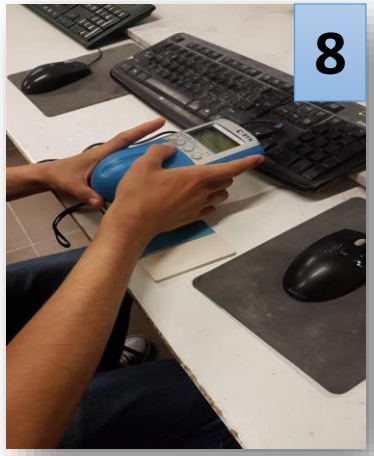


Machine to make biscuits (tiles)

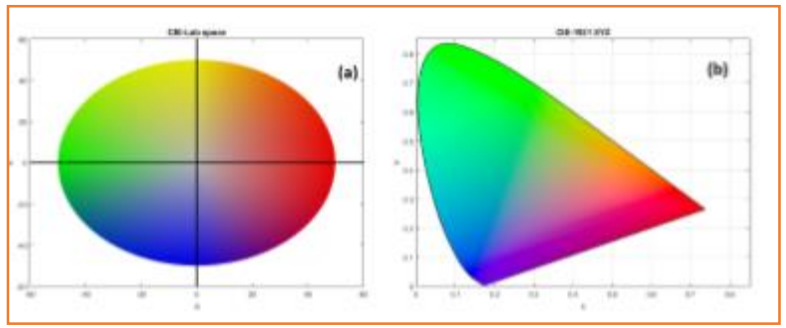
Biscuits dipped into glaze mixtures (matte or glossy, containing various concentrations of pigments)



Biscuits (Tiles) fired in the oven for 6 hours



Colorimeter used to measure the L, a, b of each tile



Used Commission Internationale de lEclairage L, a, b Coordinates (three-dimensional Lab colour space) to identify colour differences where L* indicating lightness, a* is the red/green coordinate, and b* is the yellow/blue coordinate.

Objectives

- Collect experimental data in a standard format
- Improve the accuracy of the colour prediction and correction processes by implementing mathematical models
- Mathematical Models

  1. Taguchi method
  - Orthogonal arrays
  - Signal to noise ration (S/N)
  - Analysis of variance (ANOVA)

  2. Regression and cross-validation techniques
  - predict sample colour measurement
  - Based on statistical package R

- Implementation
  - MATLAB, Excel, R
  - Graphical user interface (GUI)
  - Colorimeter: colour differences between the sample and standard (L, a, b)
  - Export Taguchi methods' results to Excel

Project 1. Taguchi's Method

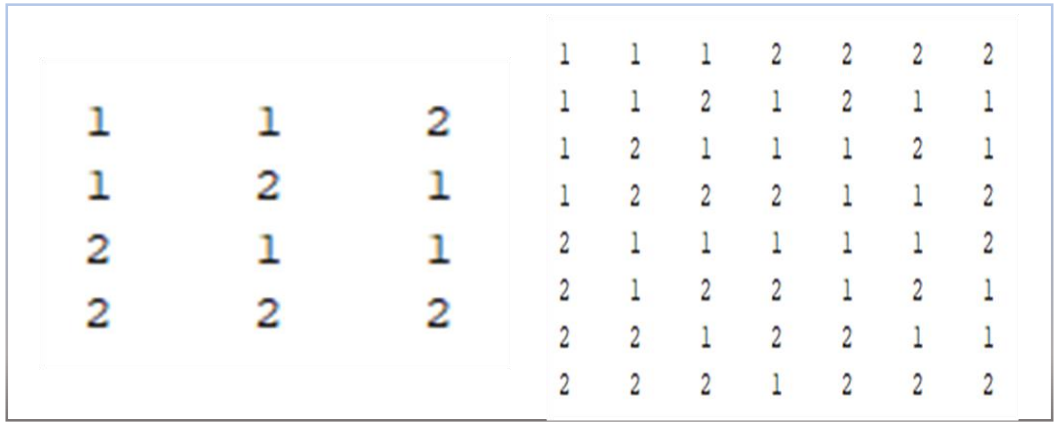
- Robust design technique (Japanese statistician Genichi Taguchi) applied to Engineering, biotechnology, marketing and advertising etc.

- Allows:
  - To study the effect of individual factors on the performance
  - To determine which factors most influence the product quality
  - To adjust the design parameters to their optimal levels
  - To define how well the process is functioning

- Key technical features:
  - Orthogonal arrays
  - Signal to noise ration (S/N)
  - Analysis of variance (ANOVA)
  - Implemented for this project in MATLAB

- Creating superior production processes with a minimum amount of experimentation, thus saving time, cost, resources

Orthogonal arrays



1	1	2
1	2	1
2	1	1
2	2	2

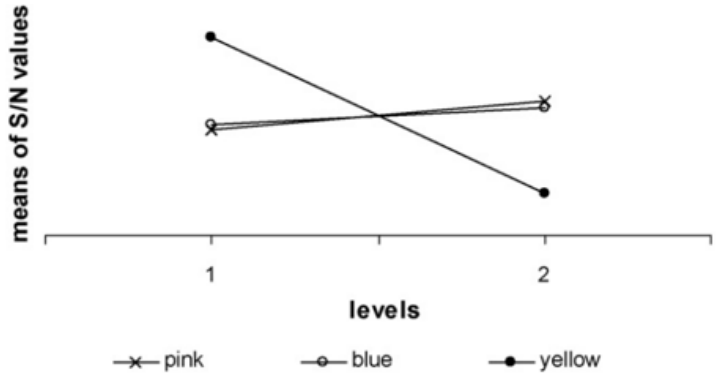
1	1	1	2	2	2	2
1	1	2	1	2	1	1
1	2	1	1	1	2	1
1	2	2	2	1	1	2
2	1	1	1	1	1	2
2	1	2	2	1	2	1
2	2	1	2	2	1	1
2	2	2	1	2	2	2

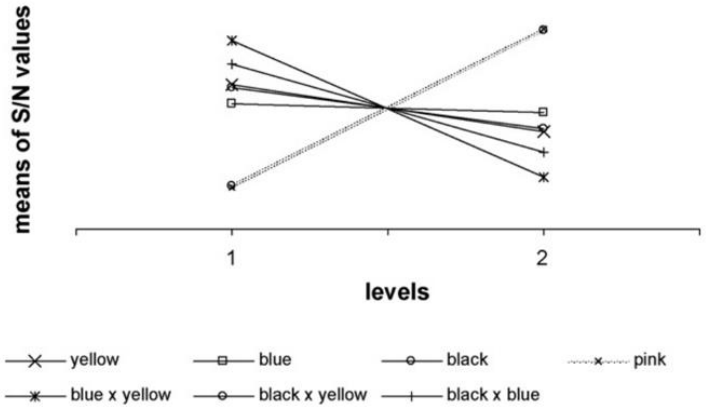
- Special standard experimental design requiring small number of experimental trials to find the main factors effects on output
- Organise the factors (affecting the process and the levels at which they should be varied)
- Choice depends on the number of controllable factors and levels
- Allows evaluating the interaction between factors, particularly important in case of formulation of colours
- Taguchi arrays: L4(2^3) (3 factors and 2 levels), L8(2^4) (4 factors and 2 levels)

Signal-to-Noise Ratio (S/N)

- Quantifies the variation between the **target value** and the **obtained result**.

- Three categories of the performance characteristics in the analysis of the S/N ratio:
  1. **the lower-the-better**
  2. the higher-the-better
  3. the nominal-the-better
- Depends on the quality characteristics of the product/process to be optimised
- Uses mean and the variability of the experimental result
- The optimal level of each factor is the level with the highest S/N ratio mean.





ANOVA TESTS

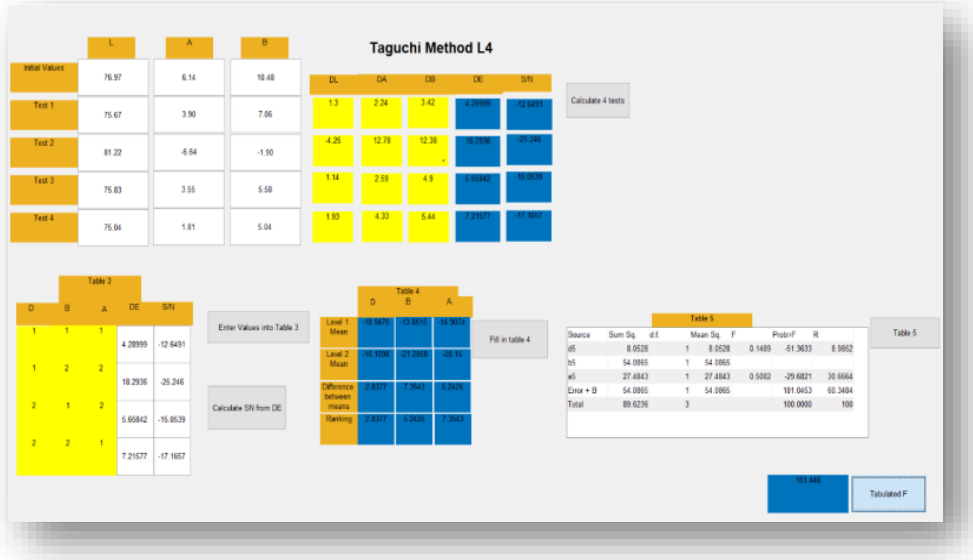
- Help choosing pigments with significant influence on the desired colour.
- N-way ANOVA

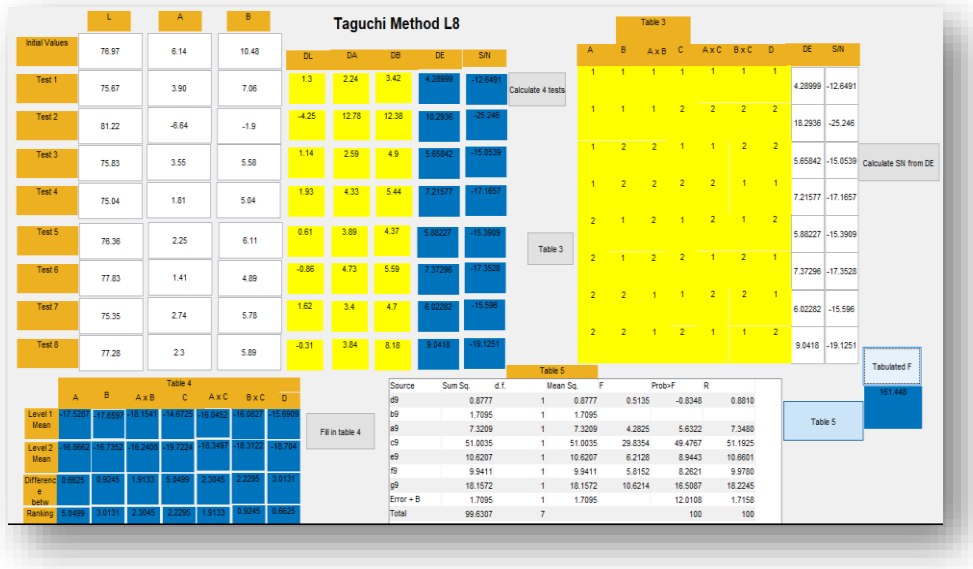
'Source'	'Sum Sq.'	'd.f.'	'Mean Sq.'	'F'	'Prob>F'	'R'
'D'	[0.8603]	[1]	[0.8603]	[3.1400]	[2.1658]	[3.1778]
'B'	[0.2740]	[1]	[0.2740]	[]	[]	[]
'A'	[25.9392]	[1]	[25.9392]	[94.6685]	[94.7981]	[95.8101]
'Error + B'	[0.2740]	[1]	[0.2740]	[]	[3.0362]	[1.0121]
'Total'	[27.0735]	[3]	[]	[]	[100]	[100]

- Variance of B is the lowest, thus pooled in the error
- Contribution of pigment A is 95%
- Only this factor's F-value higher than the tabulated one for a 95% confidence level (161.44).
- Thus, the quantities of the other pigments on the final combination can be the lower ones, hence reducing costs
- Therefore, the best combination for this glaze is D1B1A1.

Graphical user interface (GUI)

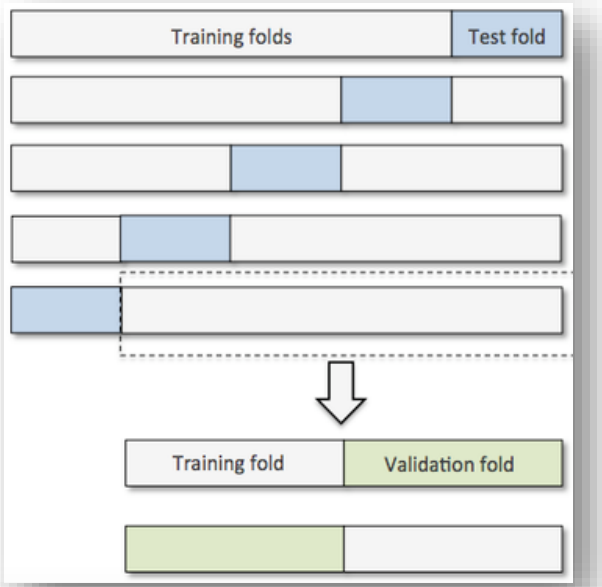
- Built using MATLAB software
- User-friendly
- Provide immediate, visual results for each action.
- Allows multiple programs to be displayed simultaneously.
- Users do not need to know any programming languages.
- Exporting to Excel files

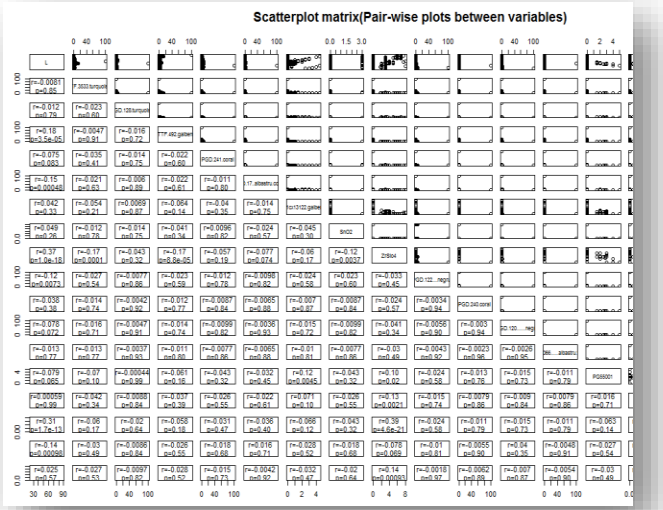




Project 2: Regression & Cross-Validation

- Data cleansing & merging
- Prediction of sample colour measurement using pigments data
- Different Regression (linear, random regression forest, ridge, lasso etc.) & CV techniques (Hold-out, Leave-one-out, K-fold etc.) have been used to measure the accuracy of the models
- Implemented in R






```
lm(formula = L ~ ., data = selectedData)

Residuals:
   Min     1Q Median     3Q    Max
-51.85 -14.73   0.12  10.42  40.26

Coefficients:
                            Estimate Std. Error t value Pr(>|t|)
(Intercept)                 46.8372     1.0505   44.59  < 2e-16 ***
TTF.3533.turquoise           0.1951     0.1444    1.35   0.1772
PGD.128.turquoise            0.0389     0.1556    0.25   0.8028
TTF.492.galben               0.9318     0.1451    6.42  3.0e-10 ***
PGD.241.coral               -0.2034     0.1536   -1.32   0.1859
PGD.17..albastru.cobalt     -0.4624     0.1555   -2.97   0.0031 **
X1cx13122.galben             3.2033     1.1532    2.78   0.0057 **
SnO2                         4.0240     1.3857    2.90   0.0038 **
ZrSio4                       2.6669     0.3180    8.39  4.7e-16 ***
PGD.122....negru            -0.4148     0.1551   -2.68   0.0077 **
PGD.240.coral               -0.1108     0.1567   -0.71   0.4798
PGD.120.......negru         -0.2239     0.1564   -1.43   0.1529
PGD.066......albastru.verzui 0.0093     0.1567    0.06   0.9527
PG55001                     -2.9749     1.0557   -2.82   0.0050 **
PGE.5617                    -3.0688     2.8749   -1.07   0.2863
PGD.146                    113.3875    25.7146    4.41  1.3e-05 ***
PGD.118                     -6.3365     2.3964   -2.64   0.0084 **
ttf.136                     -4.3084     7.0994   -0.61   0.5442
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Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
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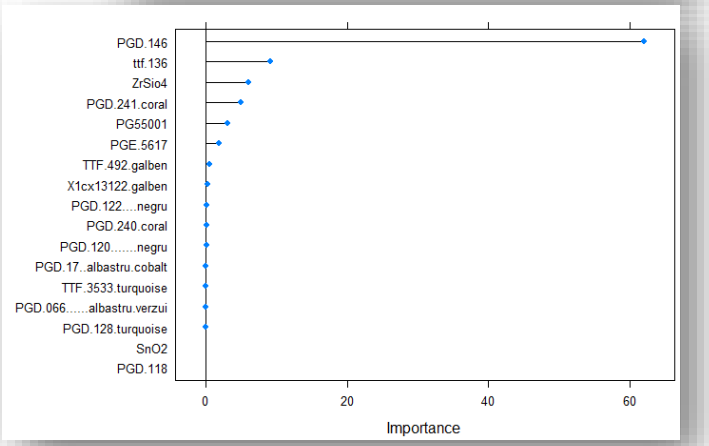

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Future Work

- Orthogonal Array L9 (3*3) using (3 pigments, 3 levels)
- Orthogonal array L9 (3^4) using 4 pigments and 3 levels

- Further use of data mining and machine learning techniques to solve the problem of automatic design and correction of ceramic colours.

- Deep learning techniques.

Thank you!

Any Questions?