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To cite this article: K Komisarczyk and R Dachowski 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **214** 012094

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A Decision Making Trial and Evaluation Laboratory method - key criteria in the selection of bricks.

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Abstract. Depending on the place of residence, social status, education or preferences, investors make various decisions regarding the construction material. As far as the functional characteristics of individual materials are known, the factors that govern decision-makers in the choice of construction material for building construction are not fully known. In the article, the authors have therefore attempted to find these criteria and to investigate causal relationships between compressive strength, acoustic insulation, economy, ecology, thermal conductivity and fire safety. The main aim of the article is also to find answers to the following questions: which criterion is decisive? What impact do the individual criteria have on each other? Whether and to what extent ecology influences on the decisions that are made? Unlike the traditional multiple criteria decision-making techniques which typically assume the criteria are mutually independent. By applying DEMATEL method, the importance of six criteria can be determined and the causal relations among the criteria can be constructed. The most important factor in the choice of construction material is price, and in the second place is ecology. The compressive strength (K1) and thermal conductivity (K5) have a strong impact on the other criteria. K1, K2, K5 and K6 have a strong impact on ecology (K4) and economy (K3). However, it should be emphasized that the least affect by fire safety (K6) and sound insulation (K2).

1. Introduction

The market for construction materials used for erecting buildings in traditional brick technology is rich in products made of ceramics, expanded clay, cellular concrete or lime-sand products.

Cellular concrete blocks have the best thermal insulating power among the structural materials with the strength of 2 N/mm². Using them saves the time in the process of building a house mainly because of omitting the stage of thermal insulation, easy manner of bricklaying and the reduction of the risk of faulty performance. The ceramic bricks are also used for building single-leaf walls. They provide healthy microclimate in a room, thanks to the "breathing" of the walls, heat accumulation and the parameters of thermal insulating power. These bricks are ecological products, they do not cause any environmental pollution - they are appropriate for complete recycling.

Sand-lime products are characterised by high level of ability to accumulate heat and it directly results from its large mass. A high level of thermal resistance of the walls makes those walls play a role of a thermal buffer and they level the effects of rapid temperature changes outside and inside of the buildings. During the winter, when they are quickly heated, they give up the heat for a long time, and during the summer, when the level of sunlight is high, they do not dramatically react to the temperature that is outside, but they absorb it slowly in order to give it slowly up during cooler time. This property is the reason for the fact that the temperature inside the rooms is maintained on a mild, healthy for body level. High energy saving and thermal security of the sand-lime consist of several elements: the easiness of making thermal insulation, saving of the production costs of masonry units,



building and exploitation of the built structure [1]. The production of sand-lime is ecologically neutral in comparison with many energy-saving systems because, among others, in the exothermic reaction of lime hydration processes, a part of thermal energy used in the production process is created [2-4].

Due to the fact that there is a significant increase in the interest of sand-lime products in investors, and because they are considered one of the most ecological in this work, they have been discussed in a wider scope. Depending on the place of residence, social status, education or preferences, investors make various decisions regarding the construction material. As far as the functional characteristics of individual materials are known, the factors that govern decision-makers in the choice of construction material for building construction are not fully known. In the article, the authors have therefore attempted to find these criteria and to investigate causal relationships between these criteria. The main aim of the article is also to find answers to the following questions: which criterion is decisive? What impact do the individual criteria have on each other? Whether and to what extent ecology influences on the decisions that are made?

2. Research methodology

2.1. Criteria

The selection of criteria for testing cause-and-effect relationships is not a standard set of criteria used for such studies. The selection of features was made on the basis of surveys conducted among investors. The following criteria were therefore analyzed in the work:

K1-compressive strength. Considering lime-sand products, in the domestic industry conditions, bricks with a compression strength class of 20 or 25 MPa are obtained. On the building materials market, however, there is a demand for lime-sand products with strength characteristics corresponding to class 35 and higher. The improvement of these features can be achieved in several ways. However, they are a function of many factors, both physical (physical properties of quartz sand, conditions and method of forming products) as well as chemical factors (chemical composition of aggregate and binder, molar ratio CaO/SiO_2 , conditions of hydrothermal treatment - pressure and curing time) [5, 6]. The endurance criterion will affect the durability of the partition and thus the safety of use. It should be noted, however, that the compression strength parameter is the most important in constructing several-storey buildings.

K2-acoustic insulation. It is basically dependent on such physical features as: volumetric weight, porosity, elasticity expressed by the modulus of elasticity and the damping coefficient of the internal sound in the material [7]. Analyzing sand-lime products, it can be concluded from the available literature that the improvement of acoustic parameters of bricks is achieved thanks to the use of heavy aggregates: barite and basalt. Meeting the requirements of acoustic insulation is necessary to ensure adequate comfort for residents.

K3-economy. In the under consideration analysis, the economics does not only mean the price per m^2 of material or price for labor. Investors link the choice of solutions together with the building's operating costs in the future.

K4- ecology. In the ecological aspect, the authors took into account the energy consumption of the production process of thermal insulation materials. The possible disposal of materials created during production and the possibility of recycling are other important aspects. The chemical composition of the material is also extremely important, especially the content of harmful substances. The location of the raw material and the processing plant is connected with additional environmental pollution forced by the necessity of long transport. Product life cycle (its operation, durability) and impact on the environment and the user (in the implementation process and during use, including the need for maintenance).

K5-thermal conductivity. The basic disadvantage in the case of sand-lime products should be considered unfavourable thermal properties, manifesting themselves in a relatively high value of the thermal conductivity coefficient λ . The value of this coefficient for sand-lime products obtained in a traditional way is at the level of $0.8 - 1.0 \text{ W/m} \cdot \text{K}$ and is one of the highest values among all commonly used wall materials. As a result, single-layer walls made of silicate elements do not meet the requirements in the field of thermal insulation, expressed in the size of U_0 heat transfer coefficient and it is necessary to heat them. The conducted research shows that in the case of lime-sand products,

the use of foamed glass granulate affects the change in the thermal conduction coefficient, which decreases with the increase in the proportion of used granulate in the mass of the finished product.

K6-fire safety. It is required that building structures in the event of fire hazard maintain the load capacity (meeting fire resistance criteria) for the time specified in regulations [8], limit the spread of smoke and fire in the facility, prevent its spreading to neighboring buildings, allow evacuation of persons at risk and conduct rescue operation. The sand-lime blocks are characterized by the reaction to fire class A1, which means that they are a completely non-flammable material. In addition, the wall made of silicates with a thickness of only 15 cm is able to maintain its capacity, tightness and insulation for over 240 minutes at full fire load.

2.2. Multi-criteria decision making - DEMATEL method

Among the methods of multicriteria analysis, the most popular are: AHP, ANP, DEMATEL, REMBRANT. The AHP (Analytical Hierarchy Process) method uses pairwise comparisons of objects within given criteria and the criteria and criteria groups themselves. In this method, criteria or their groups are assigned to each decision variant, subgroups of criteria can be assigned to groups, etc. This creates a hierarchy tree, at the top of which is the decision target, and at the bottom the criteria to which the appropriate weight is assigned. The ANP (Analytic Network Process) method is a development of the AHP method. This method allows you to define any dependencies between graph elements, regardless of the position of the elements interacting in the graph. The REMBRANT method (Ratio Estimation in Magnitudes or Deci-Bells to Rate Alternatives which are Non-Dominated) has only three levels of hierarchical structure. It doesn't have the structure of the criteria itself. The DEMATEL (Decision Making Trial and Evaluation Laboratory) method was used for the study, giving the opportunity to study phenomena through cause and effect analysis. This method will allow to get answers to the questions about how individual criteria affect each other and which of them is the most important [9,10]. The calculation algorithm in the DEMATEL method was divided into five stages.

In the first stage, a cause-and-effect graph was developed.

In the second stage, a direct impact matrix (matrix A) was created. In a square matrix, which is a symmetric matrix, the rows are dedicated first, whereas the columns are dedicated to the criteria that appear in the comparisons as the second.

In the third step, the matrix A was normalized in accordance with the formula (1,2) [11]:

$$BN = \frac{1}{\lambda} A \quad (1)$$

$$\text{where: } \lambda = \max\{\max_j \sum_{i=1}^n a_{ij}; \max_i \sum_{j=1}^n a_{ij}\} \quad (2)$$

BN- normalized matrix A

i- row of the table

j- column number

In the fourth stage, a total impact matrix was created (3), denoted by the symbol T. The total impact matrix determines both the direct and indirect influences of individual criteria.

$$T = BN + P \quad (3)$$

where: P - indirect impact matrix, determined in accordance with the formula (4):

$$P = BN^2 (I - BN)^{-1} \quad (4)$$

I- the unity matrix

The fifth stage takes into account the determination of the indicators of the meaning of t_i^+ (5) and the ratios of the relation t_i^- (6) [12].

$$t_i^+ = \sum_{j=1}^n t_{ij} + \sum_{j=1}^n t_{ji} \quad (5)$$

$$t_i^- = \sum_{j=1}^n t_{ij} - \sum_{j=1}^n t_{ji} \quad [4] \quad (6)$$

In the last stage, a dependency graph was created based on the obtained results.

3. Research results

All participants in the investment process took part in the survey. Each expert determined the impact strength of the criteria on a scale of 0-4 (0 - no impact, 1- very low impact, 2- low impact, 3- high impact, 4 - very high impact). Based on the matrix of direct influence, a cause-and-effect plot was established (Figure 1). Relationships between individual criteria have been assigned numerical assessments. Graphical changes of the lines, presented in Table 1, mean assigning the impact of a given criterion to the remaining criteria. Generally, these pair of criteria K2 and K5, K3 and K5, K3 and K4, K3 and K1, K1 and K4 is mutually influenced by each other. There are no direct dependence between K5 and K6, K2 and K6, K2 and K4. Criterion K6 (fire safety) is more independent compared with the other criteria.

Table 1. Changes in graphic lines and the associated criteria.

Criterion	The type of line used
K1	Solid line
K2	The dotted line
K3	Wave-shaped line
K4	Line with a dash-dot-dash layout
K5	Line with „x” signs
K6	Line in the shape of a zigzag

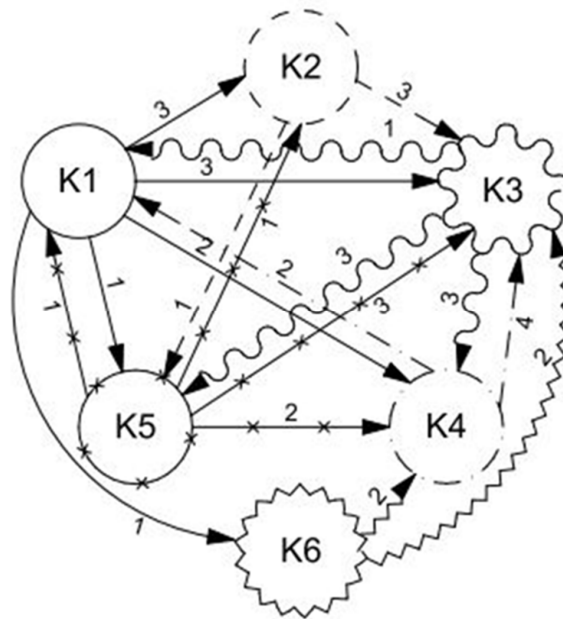


Figure 1. The cause-effect graph.

The matrix A of direct influence was calculated to the normalized initial direct-relation matrix BN.

$$A = \begin{bmatrix} 0 & 3 & 3 & 2 & 1 & 1 \\ 0 & 0 & 3 & 0 & 1 & 0 \\ 1 & 0 & 0 & 3 & 3 & 0 \\ 2 & 0 & 4 & 0 & 0 & 0 \\ 1 & 1 & 3 & 2 & 0 & 0 \\ 0 & 0 & 2 & 3 & 0 & 0 \end{bmatrix}$$

$$BN = \begin{bmatrix} 0 & 0.2 & 0.2 & 0.13 & 0.07 & 0.07 \\ 0 & 0 & 0.2 & 0 & 0.07 & 0 \\ 0.07 & 0 & 0 & 0.2 & 0.2 & 0 \\ 0.13 & 0 & 0.27 & 0 & 0 & 0 \\ 0.07 & 0.07 & 0.2 & 0.13 & 0 & 0 \\ 0 & 0 & 0.13 & 0.2 & 0 & 0 \end{bmatrix}$$

On the basis of the direct influence matrix, the indirect influence matrix P

$$P = \begin{bmatrix} 0.07 & 0.02 & 0.17 & 0.12 & 0.09 & 0 \\ 0.03 & 0.01 & 0.05 & 0.07 & 0.05 & 0 \\ 0.06 & 0.04 & 0.16 & 0.08 & 0.04 & 0.01 \\ 0.04 & 0.04 & 0.09 & 0.11 & 0.09 & 0.01 \\ 0.06 & 0.03 & 0.12 & 0.09 & 0.08 & 0.01 \\ 0.05 & 0.01 & 0.09 & 0.06 & 0.05 & 0 \end{bmatrix}$$

and the matrix of the total influence T were calculated.

$$T = \begin{bmatrix} 0.07 & 0.22 & 0.37 & 0.25 & 0.16 & 0.07 \\ 0.03 & 0.01 & 0.25 & 0.07 & 0.12 & 0 \\ 0.13 & 0.04 & 0.16 & 0.28 & 0.24 & 0.01 \\ 0.18 & 0.04 & 0.36 & 0.11 & 0.09 & 0.01 \\ 0.12 & 0.1 & 0.32 & 0.23 & 0.08 & 0.01 \\ 0.05 & 0.01 & 0.23 & 0.26 & 0.05 & 0 \end{bmatrix}$$

The obtained matrix P defines only indirect influences, therefore, the values in the P and T matrices are the same wherever in the BN matrix are zero. The values of the matrix T indicate the degree of influence of the criteria on each other, it takes into account both direct and indirect impacts [4,12]. From here, it can be seen that all impact values have increased. The increase in value is slight. Due to the large amount of direct influence between criteria, indirect influences don't play a key role. It can be noticed that the influence of K1 on K3 increased from 0.2 to 0.37. This is due to the fact that K1 has a high impact on K2 (at 0.22). K2 has a large impact on K3, which consequently gives indirect influence K1 on K3. In turn, the influence of K4 on K5 increased from 0 to 0.09. The reason for this is the very large impact of K4 on K3 (0.36), K3 has a high impact on K5, which causes a large indirect influence of K4 on K5. There are many more influences. In order to conduct a collective analysis of all impacts, the indicators of the significance of t_i^+ and the ratios of the relationship t_i^- were determined for each criterion.

Table 2. The sum of influences given and received among six criteria.

Criteria	t_i^+	t_i^-
K1 (Compressive strength)	1.72	0.56
K2 (Sound insulation)	0.90	0.06
K3 (Economy)	2.55	-0.83
K4 (Ecology)	1.99	-0.41
K5 (Thermal conductivity)	1.60	0.12
K6 (Fire safety)	0.70	0.50

Based on the Table 2, the importance of the six criteria can be prioritized as $K3 > K4 > K1 > K5 > K2 > K6$ based on t_i^+ values, where economy is the most important criterion with the value of 2.55, where fire safety is the least important criterion with the value 0.70. Positive values t_i^- have: compressive strength, sound insulation, thermal conductivity and fire safety. Negative values have economy and ecology. According to the Figure 2, the compressive strength (K1) and thermal conductivity (K5) have a strong impact on the other criteria. K1, K2, K5 and K6 have a strong impact on ecology (K4) and economy (K3). However, it should be emphasized that the least affect by fire safety (K6) and sound insulation (K2).

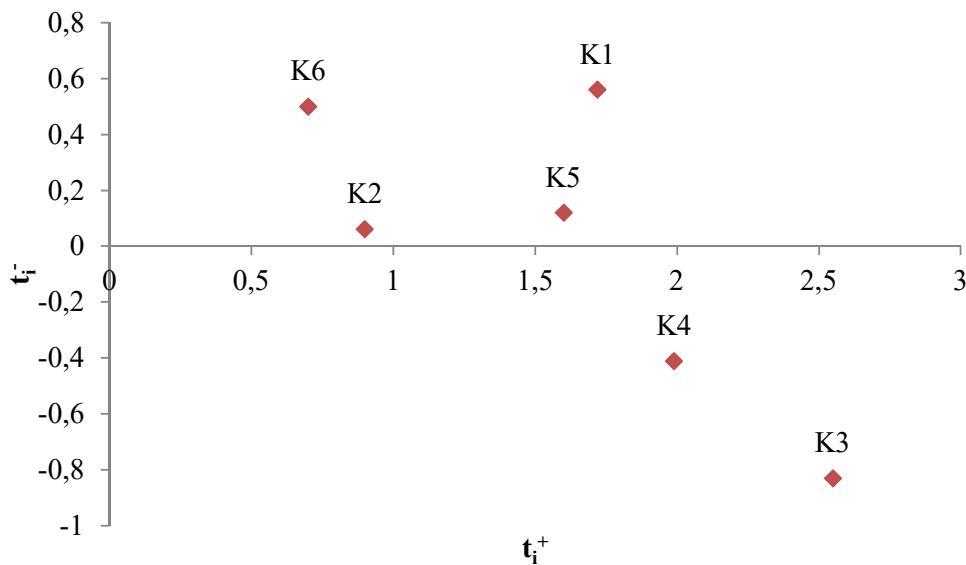


Figure 2. The graph of showing causal relations among these six criteria.

4. Conclusions

Unlike the traditional multiple criteria decision-making techniques which typically assume the criteria are mutually independent; DEMATEL method does not require this assumption but further helps the decision makers in identifying the casual relationships among criteria. By applying DEMATEL method, the importance of six criteria can be determined and the causal relations among the criteria can be constructed.

The results show that:

- the most important factor in the choice of construction material is price, and in the second place is ecology (high t_i^+ values prove this). K4 (ecology) and K3 (economy) are, however, below the OX axis, therefore other criteria strongly affect them;
- the compressive strength (K1) and thermal conductivity (K5) have a strong impact on the other criteria;
- K1, K2, K5 and K6 have a strong impact on ecology (K4) and economy (K3). However, it should be emphasized that the least affect by fire safety (K6) and sound insulation (K2).

To sum up the above, for investors and designers, ecology (including economics) is one of the decisive factors in the selection of building materials. The increase interest in sand-lime products is justified, and the development of the scientific sphere is important and necessary.

References

- [1] Sze S M 1969 *Physics of Semiconductor Devices* (New York: Wiley–Interscience)
- [2] Dorman L I 1975 *Variations of Galactic Cosmic Rays* (Moscow: Moscow State University Press) p 103
- [3] Grupa Silikaty 2016 *Technical Catalog of Silicate Products* p 24
- [4] Stępień A 2017 *The Impact of Glass Additives on the Functional and Microstructural Properties of Sand-Lime Bricks* International Journal of Civil and Environmental Engineering vol4pp 1-5
- [5] Stępień A, Kostrzewa P 2017 *Autoclaved Sand-Lime Products with a Polypropylene Mesh* Materials Science and Engineering vol245
- [6] Pytel Z 2014 *Modification of the Phase Composition and Microstructure of Autoclaved Sand-Lime Materials* (Cracow) Ceramic Polish Publisher
- [7] Małolepszy J 2013 *Basics of Building Materials Technology and Research Methods*. AGH Publishing House (Cracow)pp 165-166

- [8] Sastry B S R 2014 *Investigations on Sand Lime Bricks—Part I* 2014 Transactions - Indian Ceramic Society vol 10 pp62-67
- [9] Szudrowicz B 2006 *Assessment of Acoustic Insulation an Example Wall Solutions The Intermediate Families in the Mountained Currently Multiple Buildings* Building Research Institute - Quarterly No 1 vol 137 pp 40-43
- [10] Regulation of the Minister of Infrastructure of April 12, 2002 on Technical Conditions that Should Be Met by Buildings and Their Location, with later d.
- [11] Dytczak M, Ginda G, Wojtkiewicz T 2011 Analysis of Cause and Effect Relationships in Structural Failure Using the DEMATEL Method XXV Scientific and Technical Conference pp 419-426.
- [12] Hsu C-W, Kuo T-C, Chen, S-H, & Hu, A H 2013 *Using DEMATEL to Develop a Carbon Management Model of Supplier Selection in Green Supply Chain Management* Journal of Cleaner Production vol 56 pp 164–172
- [13] Nermend K 2017 *Metody analizy wielokryterialnej i wielowymiarowej we wspomaganiu decyzji* (Warsaw) PWN Publishing house
- [14] Wu, H.-H., & Chang, S-Y 2015 *A Case Study of Using DEMATEL Method to Identify Critical Factors in Green Supply Chain Management* Applied Mathematics and Computation vol 256 pp 394–403