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CAUSE-AND-EFFECT ANALYSIS OF ANTHROPOGENIC AND NATURAL ASPECTS IN THE PROCESS OF ASSESSING THE MATERIAL HERITAGE RESOURCE IN UNDERGROUND MINING ADAPTATION PLANNING

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Abstract

The ongoing energy transformation requires legal and economic intervention by the Polish government to phase out unprofitable mining enterprises, especially in the coal mining sector. The poorly executed process mentioned above may lead not only to environmental degradation but also to social problems (rupture of interpersonal relationships, elimination of traditions, eradication of cultural behaviors). Therefore, an effective solution to this problem may be the adaptation of the aforementioned facilities for tourism purposes. These facilities have significant potential related to mining heritage and geodiversity. The article defines basic criteria related to mining heritage and examines the cause-and-effect relationships using the DEMATEL method. The outcome of this process will be an attempt to develop requirements for anthropogenic intervention in underground excavations in interaction with the preservation of cultural, material, and geodiversity heritage (master plan).

Keywords: analysis, adaptation, underground mining heritage, heritage preservation, DEMATEL

1. INTRODUCTION

Underground and rock mining has paved the way for progress in construction and architecture throughout the centuries. Currently, in many European countries, after the extraction of natural resources has ceased (abandoned mines) and underground engineering structures and facilities (sanitary channels, pumping stations, railway tunnels, etc.) have been closed, their reutilization as strategic cultural and natural heritage is taking place.

This is associated with both economic factors (maintenance of inactive facilities) and social factors (activation of local communities). The result of such actions is the design of adaptations for underground spatial structures, catering to the needs of local communities. Contemporary efforts are being made to activate the cultural and social potential of historic underground excavations by not only making the facilities accessible but also changing their purpose of use, such as for tourism, therapeutic, religious, scientific and educational, exhibition, conference, sports, recreational, etc. purposes [1].

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Poland, as a member of the European Union, is obligated to secure and protect underground heritage sites as natural and cultural heritage, which forms the foundation of our shared identity based on the multidirectional flow of ideas and technologies in the process of exploiting the natural environment [2]. The process of securing and making historic underground spaces available for new functional purposes is developing very intensively. Currently, the number of completed or ongoing projects exceeds 50 [3]. Around the world, we can also observe the adaptive process of post-mining areas, including sites located in Germany, France, the Netherlands, and the United Kingdom [4], [5], [6], [7].

The diversity of underground structures and their specific characteristics require an individual approach to evaluating an investment program implemented in each facility. For this reason, the focus of this study was on anthropogenic underground excavations. Due to the distinctiveness and nature of each underground structure, which has its own genesis, size, depth, spatial geometry, and was created in different geological environments, there is difficulty in developing an objective method for assessing the material heritage resource. This assessment should serve as the basis for determining the hierarchy of material values, enabling the formulation of an interdisciplinary program for the protection of existing underground heritage and the coordination of its principles with mining methods during the process of changing the use of underground excavations. The programmatic basis for intervention in the rescue and adaptation process should involve the implementation of contemporary conservation theories and international directives regarding the preservation of cultural and natural heritage. This element appears to be crucial due to the lack of coordinated legislation concerning, on the one hand, the technical aspects of contemporary interventions in the structures of historic underground spaces (with a priority on safety and the impact of geological structure securing methods), and on the other hand, the introduction of new functions into the specific spatial structure of underground facilities [8].

Underground mining heritage constitutes an inherent component of cultural and natural heritage. Due to the specificity of this heritage, which is an example of the synergy between human activity and the natural environment, the definition of the assigned values (characteristics) that unambiguously describe its identification serves as the basis for all decisions in the process of not only it's *in situ* preservation but also the utilization of its resources [9].

Historic underground structures materialize retrospective values - historical, artistic, technological, geo-diversity, and social values. These values undergo continuous changes during the exploitation of underground facilities, resulting in the modification of their functions. In the adaptive process, introducing a new function allows not only the preservation of anthropogenic and natural heritage but also the utilization of the potential of prospective values represented by a particular structure (economic and educational values). As a consequence, this contributes to the development of the identity of local and regional communities [10].

2. THE RESOURCE OF MATERIAL, IMMATERIAL, AND NATURAL VALUES OF UNDERGROUND MINING HERITAGE

The fundamental premise of contemporary thinking about the preservation of heritage objects should be its holistic perception as a unique component of cultural heritage that encompasses a wealth of values, history, content, and meanings, and operates within a broad social context. Each underground object contains a different set of values. The basis for the strategy of changing the use of underground structures should involve recognizing the specificity of the object and attempting to determine not only the scope and subject of preserving its heritage resources but also establishing priorities, i.e., overarching goals of the undertaken actions. However, the individualization of conservation solutions cannot imply arbitrariness in making decisions regarding the monument [11], [12]. The initiated intervention must primarily honor and enhance existing values, avoiding solely their exploitation and degradation. Valorization should be a process of recognizing cultural values through their cyclically deepened interpretation and reinterpretation along with the acquisition of new data and information. Currently, heritage values are broadly understood and extend beyond the traditional boundaries of monuments or museum collections. They also encompass cultural and natural heritage, intangible heritage values, landscapes and ecosystems, as well as digital heritage.

The attributes of value associated with a given underground object constitute an extensive set of characteristics, such as integrity, authenticity, historical significance, aesthetic value, geodiversity, and more. These attributes encompass features that indicate that a particular object can be classified as a heritage site.

According to *the Act of 23 July 2003 on the Protection and Care of Monuments* [13], requirements are imposed on heritage objects to possess at least one of the following values: historical, artistic, or scientific. The current legislation on monument protection introduces so-called undefined concepts and general clauses. This legal system is more flexible and provides a better response to the actual situation, while also allowing for the necessary independence dictated by the specificity of monument protection. Each situation should be evaluated individually, taking into account the condition of the object, its historical, artistic, scientific, and other values [14]. In this context, the aim of this study is to present the causal-effect analysis of factors enabling the assessment of the material heritage resource of underground objects as an objective process that serves as the basis for changing their use.

In contemporary times, heritage is not merely a reactive act of reviving the past, but also *"a process of engagement, communication, and meaning creation for the present and future."*.[2]

In the reference documents [15], the specification of values primarily pertains to the heritage of technology, which includes:

- industrial heritage (industrial archaeology)
- engineering heritage
- technical heritage.

However, this classification is insufficient in the context of underground structures. It does not consider an essential component of this heritage, namely geodiversity and its impact on anthropogenic intervention (the selection of technical means and technologies in the creation and operation of underground structures). Another important aspect of assessment is the emphasis on the significance of immaterial values, which are integrally linked to the material heritage, as defined in the UNESCO Convention [16]. These so-called values of social identity include:

- oral traditions and expressions, including language as a tool of transmission
- performing arts (such as traditional music, dance, and theater)
- customs, rituals, and festive events
- knowledge and practices concerning nature and the universe, traditional craftsmanship.

The valuation of underground spatial structures, as well as the technical and technological aspects implemented in their creation and operation, forms the basis for the preparation and implementation of an investment task, such as a change of use. Valuation in terms of conservation and adaptation is a "*cognitive process of value assessment and includes a series of analytical sequences such as identification, research, interpretation, definition, redefinition, and evaluation of individual values*" [17].

[2] Smith L., Uses of heritage. Routledge: London, 2006.

An evaluative analysis of an underground object in the context of its retrospective values, encompassing all components of cultural heritage related to its transformation over time, includes not only material but also immaterial aspects (Table 1).

Table 1. Retrospective values of underground mining heritage

Retrospective values	
Material characteristics	**Non -material characteristics**
authenticity	social identity
integrity	
uniqueness	
artistic value	
historical value	

In the process of valuation, a fundamental element is the definition of so-called components of underground heritage. The material values include:

- technology of geological environment exploitation,
- safety systems (structural elements - enclosures, escape systems - evacuation plans, etc.),
- environmental hazard elimination technologies (drainage, ventilation, primary and traditional warning systems - canaries, etc.),
- form and geometry of underground spaces (corridors, tunnels, chambers, adits),
- technical and technological equipment (power supply systems including lighting, production devices, transportation, etc.),
- artistic heritage (sculpture, small architecture, interior decoration, etc.),
- landscape heritage (impact of the object's shaping on the transformation and creation of new cultural values in the context of changes in historical natural, urban, and rural landscapes).

The immaterial values include:

- intentional cultural heritage (historical conditions - economic, cultural, original function of the object),
- social identity (tradition, customs, literature).

3. CAUSAL-EFFECT ANALYSIS OF CRITERIA FOR ASSESSING THE RESOURCE OF MATERIAL HERITAGE

The authors of the article present the issue of adapting mining sites to new functions. The categories, followed by subcategories and criteria, were discussed in more detail in [3], where a multi-criteria evaluation method for adapted excavations was proposed. However, it is also necessary to analyze the mutual relationships between the criteria that will be considered in the assessment. For this purpose, the causal-effect analysis is suggested. In the literature, various methods of this type can be found, including Ishikawa diagram, 5xWhy, Pareto diagram, or Root Cause Analysis (RCA), but all of these are mostly used for detecting causes of failures/problems in production issues. A slightly different application is found in the DEMATEL method. This method involves examining the mutual influence of factors on each other, taking into account feedback. The DEMATEL method allows for determining the nature of individual criteria - causal, effectual, or mixed (relational) relationships, as well as the strength of the impact of individual factors on others (position). Therefore, the authors propose using the DEMATEL method to analyze mutual relationships and determine the nature of the presented assessment criteria. Additionally, this not only describes the relationships between the specified criteria but also has an impact on the practical application of mining protection methods (e.g., mining structures) due to the preservation of cultural heritage.

Due to the large number of factors presented in the monograph [3], it was decided to examine the relationships between selected and, at the same time, the most important assessment categories. The analysis focused on three key components characterizing the material retrospective values of underground excavations: authenticity, integrity, and uniqueness. These components encompass the most important aspects describing the components of anthropogenic and natural heritage. Non-material values were deliberately omitted due to their minimal influence on decision-making regarding the adaptation process. They serve as a complementary component, adding value to the base of material criteria. While not diminishing the importance of the aforementioned values, especially in the context of preserving social identity, each implementation of making underground excavations accessible reactivates individual identity, which includes psychological and social perspectives, as well as regional identity (geographic, ethnographic, historical, economic, political, ideological, and ecological). The above analysis belongs to the field of humanities. This means that the evaluation of social identity, as an element of a multi-criteria decision-making system, should be treated autonomously as an additional complementary aspect to the valuation system based on specific and representative measurable material characteristics of underground excavations.

The DEMATEL method was used to identify causal-effect relationships [18]; [19]; [20]; [21]; [22]. The procedure in the method will consist of the following steps [23]:

1. Compilation of criteria for assessing the material heritage resource in the process of adapting underground mining sites.
2. Development of a direct influence diagram, allowing the expression of the directed influence of the considered factors on each other in a cause-effect context. A scale with a parameter value of N = 3 (where: 0 - no influence, 1 - weak influence, 2 - influence, 3 - strong influence) was used to assess the "strength" of the influence of each factor.
3. Based on the dependencies determined using the graph, create a matrix of direct mutual influence of factors on each other A_D.

1. Determination of the normalized direct influence matrix A'_D with parameters from the interval [0,1]. The normalization factor (n) is taken as the largest sum of rows or columns of matrix A_D:

$$A'_D = \frac{A_D}{n}, \tag{3.1}$$

$$n = \max\{\sum_{i=1}^{n} a_{ij}; \sum_{j=1}^{n} a_{ij};\} \tag{3.2}$$

2. Development of the indirect influence matrix ΔT:

$$\Delta T = A'^2_D \cdot (I - A'_D), \tag{3.3}$$

3. Determination of the total influence matrix T:

$$T = A'_D \cdot (I - A'_D), \tag{3.4}$$

4. Determination of position and relation indices, expressing respectively:

s^+ - the role of a given factor in the process of determining the structure of relationships between objects,
s^- - the total influence of a given factor on the others.
These values are determined according to the formulas:

$$s^{+} = \sum_{j=1}^{n} t_{ij} + \sum_{j=1}^{n} t_{ji} = R_{T_i} + C_{T_i}, \quad (3.5)$$

$$s^{-} = \sum_{j=1}^{n} t_{ij} - \sum_{j=1}^{n} t_{ji} = R_{T_i} - C_{T_i}, \quad (3.6)$$

When these values are plotted on a graph, it becomes easy to observe which factors have the greatest influence on the others and determine which factors are causes, effects, or have a mixed nature.

5. Determination of the net influence values, which indicate which factor has the greatest influence on the others, taking into account both the causal and effect nature (Table 2):

$$netto = s^{+} + s^{-} \quad (3.7)$$

By pairwise comparing all the criteria, particularly considering the feedback loops, the DEMATEL method allows for reflecting the real relationships among the analyzed factors.

4. FACTORS THAT ARE CONSIDERED IN THE EVALUATION OF MINING SITES

The criteria grouped under three main categories, namely authenticity, integrity, and uniqueness, will be subjected to a causal-effect analysis. The assessment of authenticity is conducted in the context of contemporary times. An object can serve as evidence of mining and construction techniques and provide knowledge about its original function, even if it no longer fulfills that function currently.

For the authenticity category, the following aspects have been analyzed and selected:

- construction phases based on stratigraphic and mining studies
- dating and chronological changes in spatial dimensions over time
- types of spatial forms of excavations in the existing inventory
- types of geometric cross-section forms
- types of identified structural construction features in the underground space
- volumes and interconnections of excavations within the underground structure
- proportions of identified areas excavated using traditional and modern methods
- types and systems of technical and technological infrastructure (including the identification of production signs and labels)
- implementation of aesthetic forms in the process of facility exploitation
- list of written and oral sources of information, information contained in iconographic sources.

It should be noted that the presented categories and criteria do not refer to the condition of individual elements. This is because authenticity values are not synonymous with the assessment of the state of preservation, which should be an additional component of a multi-criteria analysis.

The integrity of a heritage site is a measure of its wholeness and completeness. In the context of underground mining heritage, its indicators are the technical and technological solutions typical of the historical process of its creation and exploitation. It represents the unity of matter, thought, and emotions. Stating the integrity of underground excavations means their ability to function, at least to the extent that illustrates the technical process of creating and operating underground structures. An inherent component of integrity is also the presentation of how people existed in the technical and mining environment.

The integrity of an object representing underground mining heritage includes functional, technological, and environmental elements such as:

- technologies for creating space and exploiting the geological environment
- machinery and equipment
- technical infrastructure
- individual miners' equipment
- production process instructions
- areas for miners, foremen, supervisors, management, and owners
- identification of socio-economic and natural hazards.

Additionally, this resource encompasses the physical work environment, including excavations, changing rooms, dining areas, etc.

The uniqueness category has a comparative-statistical character. This means that the value of uniqueness is associated with a reference scale in the context of underground objects located in a district, municipality, region, province, and, in particular cases, globally. The scope of research analysis for this criterion includes:

- Preservation of the original function over time
- Innovativeness of material and construction features
- Technological innovation in creation and exploitation methods
- Integrity of the object, equipment, decor, and infrastructure
- Technical efficiency of technological equipment illustrating the past (currently discontinued) technology
- Relict status of ownership, illustrating the former socio-economic order
- Documented connections of the object with historical events or figures

Finally, using the DEMATEL method, three categories were analyzed, divided into subcategories and criteria, as listed in Table 2.

Table 2. The set of categories, subcategories, and evaluation criteria

Category	Subcategory	Criterion
KA Authenticity	KA_1 3D structures	KA_{11} Spatial configuration of excavations
		KA_{12} Section geometry
		KA_{13} Spatial (linkage structure)
	KA_2 Technical and engineering	KA_{21} Mining technology
		KA_{22} Security systems, geometry and material (enclosures)
		KA_{23} Detail - joint structure, profile geometry
		KA_{24} Infrastructure
		KA_{25} Equipment
	KA_3 Function and use	KA_{31} Operation
		KA_{32} Continuity of service life
		KA_{33} History
	KA_4 Landscape	KA_{41} Location
	KA_5 Aesthetic features	KA_{51} The artistic decoration
KI Integrity	KI_1 Continuity of transformations	KI_{11} Creation and operation
		KI_{12} Interpretation of function
	KI_2 Inactness	KI_{21} Technical equipment
		KI_{22} Work safety
		KI_{23} Degradation of space

	KI_3 Degradation	KI_{31} Social and economic risks
		KI_{32} Environmental hazards
KU Uniqueness	KU_1 Function	KU_{11} Retaining the function
	KU_2 Innovation	KU_{21} Technology
	KU_3 Relicts	KU_{31} Social and economic conditions
	KU_4 Documenting	KU_{41} Historical
	KU_5 Geo-diversity	KU_{51} Matter
		KU_{52} Processes

5. RESEARCH RESULTS AND THEIR ANALYSIS

Table 3 presents a matrix containing the criteria, along with the determination of relationships between individual factors and the assessment of their significance. The values assigned to each relationship represent the following: 0 - no influence; 1 - small influence; 2 - moderate influence; 3 - high influence. The determination of relationships between individual factors was established by the authors of the article based on the current knowledge in the research subject area.

Table 3. Matrix of direct influence A_D

	KA_{11}	KA_{12}	KA_{13}	KA_{21}	KA_{22}	KA_{23}	KA_{24}	KA_{25}	KA_{31}	KA_{32}	KA_{33}	KA_{41}	KA_{51}	KI_{11}	KI_{12}	KI_{21}	KI_{22}	KI_{23}	KI_{31}	KI_{32}	KU_{11}	KU_{21}	KU_{31}	KU_{41}	KU_{51}	KU_{52}
KA_{11}	0	3	3	3	3	1	2	2	2	0	0	0	1	2	1	1	2	2	0	3	2	2	0	1	3	3
KA_{12}	1	0	1	2	3	3	2	1	3	1	0	0	2	2	0	1	3	1	0	2	2	3	0	0	0	0
KA_{13}	3	2	0	3	3	3	2	3	3	2	0	0	1	1	3	2	3	2	1	3	2	3	1	1	2	2
KA_{21}	3	3	2	0	3	2	3	3	2	1	1	1	0	1	1	2	3	3	0	2	2	2	0	0	0	0
KA_{22}	3	3	3	3	0	3	1	2	1	1	2	0	0	0	1	1	3	1	0	0	2	1	0	0	0	0
KA_{23}	1	2	1	1	3	0	1	1	1	1	0	0	1	0	0	0	1	0	0	0	1	1	0	0	0	0
KA_{24}	2	3	3	3	2	0	0	3	3	3	3	0	1	1	1	3	3	1	0	2	3	3	0	2	2	2
KA_{25}	3	3	3	3	3	1	3	0	3	3	2	0	1	1	1	3	3	1	0	2	3	3	0	3	0	3
KA_{31}	3	3	3	3	3	3	3	3	0	3	1	1	2	2	2	3	3	3	1	3	3	3	1	1	2	3
KA_{32}	2	2	3	3	3	1	3	3	3	0	3	1	2	2	1	3	3	3	1	3	3	3	1	3	3	3
KA_{33}	1	1	1	1	1	1	2	2	2	3	0	3	2	1	2	3	1	2	3	3	3	3	2	2	2	3
KA_{41}	1	1	2	2	2	1	1	1	3	3	2	0	1	1	1	0	1	1	3	3	1	1	3	2	2	2
KA_{51}	2	3	1	1	2	1	2	2	3	1	2	0	0	2	2	1	0	2	0	0	3	1	2	2	2	2
KI_{11}	3	3	3	3	3	2	3	3	3	3	2	2	1	0	3	3	2	2	2	3	3	2	3	2	2	2
KI_{12}	2	1	2	2	3	3	3	3	3	3	3	2	2	2	0	3	1	1	1	1	3	2	3	2	2	3
KI_{21}	1	2	2	3	3	2	3	3	3	2	3	1	1	2	2	0	3	0	0	1	3	2	0	3	1	3
KI_{22}	3	3	3	3	3	2	3	3	3	2	1	3	0	2	2	3	0	3	3	3	3	3	1	1	1	1
KI_{23}	3	3	3	2	3	2	1	3	3	3	3	1	0	2	3	2	3	0	1	3	3	3	0	2	2	2
KI_{31}	0	0	0	0	0	0	0	0	1	2	2	3	0	2	2	0	2	2	0	2	3	3	2	2	1	2
KI_{32}	3	3	3	3	3	2	2	3	3	1	2	0	1	1	1	1	3	3	1	0	1	2	1	1	1	1
KU_{11}	2	2	3	3	3	1	3	3	3	3	2	1	0	2	3	3	3	3	3	3	0	2	3	3	2	3
KU_{21}	3	3	3	3	3	3	3	3	3	3	2	1	0	2	3	3	3	3	1	3	3	0	1	2	2	2
KU_{31}	0	0	0	0	0	0	0	0	0	1	3	3	2	2	2	0	3	0	1	1	2	2	0	1	1	1
KU_{41}	3	3	3	3	3	3	3	3	3	3	2	3	3	2	2	3	0	1	1	1	3	3	1	0	2	3
KU_{51}	2	2	2	3	3	2	1	2	3	3	2	2	1	2	2	1	2	3	1	3	1	1	1	0	0	2
KU_{52}	2	2	2	2	2	1	1	1	3	1	1	1	1	1	1	1	2	2	0	3	1	1	0	0	2	0

Next, according to the DEMATEL method, calculations (1) - (7) were performed. The final results are presented in the chart (Fig. 1).

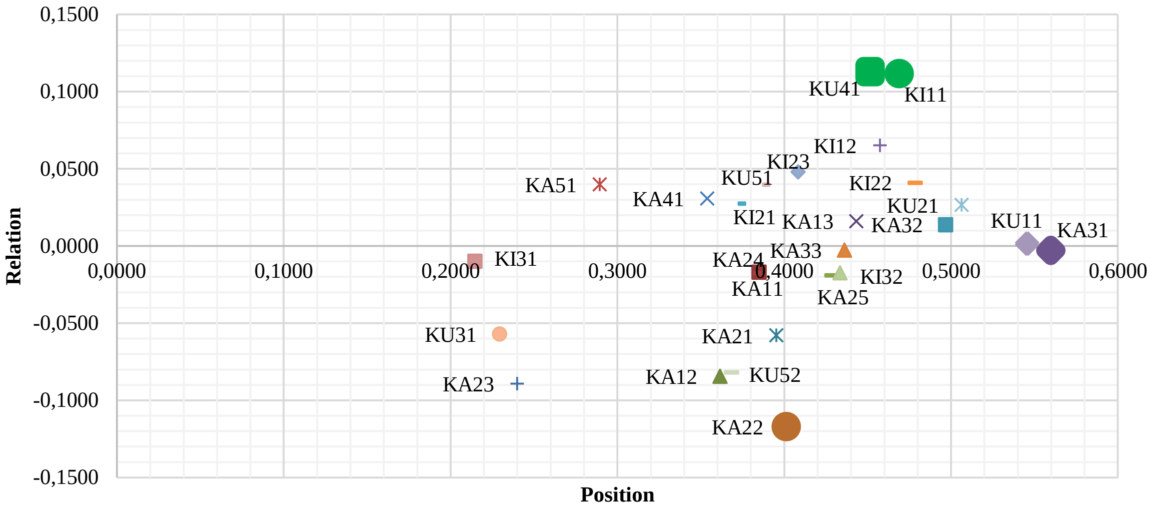

Fig. 1. The graphic interpretation of the causal-effect analysis results for the evaluation factors of mining excavations in all material categories

The causal-effect analysis showed that the most causal factors are the criteria KU_{41} (*Historical documentation*) belonging to the uniqueness category and KI_{11} (*Creation and operation*) belonging to the integrity category. *Creation and operation* determine the methods of exploitation and the modeling of underground mining excavations, and they are elements that characterize the uniqueness of the analyzed underground excavations. This factor is highly significant as it determines the use of protection technologies and the existing infrastructure equipment in mining excavations. On the other hand, *Historical documentation* relates to the duration of excavations and the change in mining technology, which is crucial in establishing the continuity of exploitation and technological development.

The most impactful factor is criterion KA_{22} (*Protection systems, geometry, and materials (enclosures)*) belonging to the authenticity category. This criterion has a strong impact because it represents the individual anthropogenic heritage in the exploitation of mining sites.

The results differ on the position axis, which illustrates the extent of influence factors have on each other. On this axis, the highest values and therefore the greatest impact on the others are exhibited by criteria KA_{31} (*Operation*) and KU_{11} (*Retaining the function*). Interestingly, both of these criteria show a mixed character in terms of their relationships. In the case of criterion KU_{11} (*Retaining the function*), the protection of the original functions in heritage objects is a priority in contemporary conservation, hence its significant impact on other evaluation criteria. This is due to the specific nature of underground mining heritage, influenced by the natural environment and anthropogenic interventions, resulting in a synergy between geological diversity and human activities. On the other hand, KA_{31} (*Operation*) illustrates the implementation of technical and technological solutions in the process of creating underground spaces (chambers, tunnels, shafts, etc.).

Additionally, in the conducted research, the authors decided to analyze the mutual interactions and determine the character within each category in order to verify whether the examined criteria still represent the same character and whether their strength of interaction decreases or increases when analyzed only within the category they belong to. Below is the linkage graph for the category of *Integrity* (Fig. 2), based on which the weights of the connections within the category were established, and similar calculations were performed using the DEMATEL method.

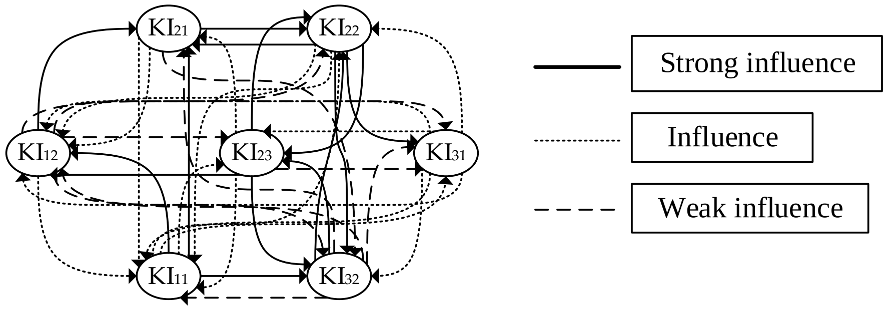

Fig. 2. Chart of direct influence - assessment results

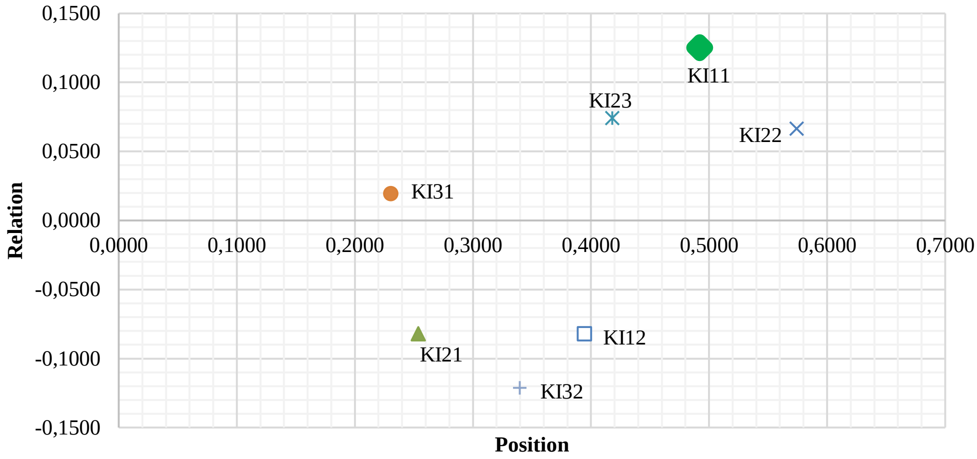

Fig. 3. Graphical interpretation of the results of the cause-effect analysis of the factors in the Integrity category

In the analysis of the integrity category (Fig. 3), it is evident that the values of individual factors have decreased. This is due to the exclusion of the influence of factors from other categories that are relevant to the assessment of mining excavations. On the position axis, which represents the nature of each criterion, the most causal character is exhibited by the criterion KI_{11} (*Creation and operation*). On the other hand, the criterion with the highest negative value, indicating the most significant impact, is KI_{32} (*Environmental hazards*).

When observing the position axis, it is noticeable that the causal criteria, including KI_{11}, have the greatest influence on the others. However, in this case, the criterion with the highest value on the position axis is KI_{22} (*Work safety*). This factor forms the basis for changing the way mining excavations are used, hence its substantial impact on the other factors.

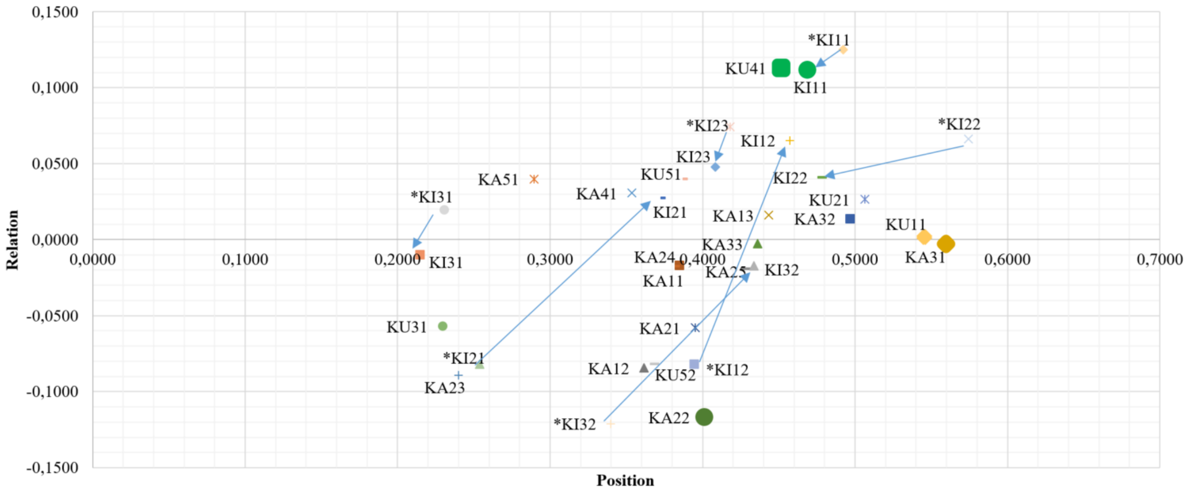

Fig. 4. The graphical interpretation of the results of the causal-effect analysis for all material categories, compared to the analysis for the Integrity category

Fig. 4 illustrates how the values and, in some cases, the character of individual factors change in the global analysis compared to the analysis of only the selected category.

In both the analysis of all categories and the selected category (*Integrity* category in the article), the key causal criterion was found to be KI_{11} (*Creation and operation*). This indicates a strong global and local causal character of this factor and highlights its significant influence on other factors, such as the use of safety technologies and the infrastructural equipment of mining excavations.

It can be observed that there is a decrease in the values on the relationship axis obtained by factors with a causal character in the global observation. This is due to the influence of factors from other categories on them, thereby diminishing their causal significance. An interesting observation is the significant change in values, which also leads to a change in the character of factors with a strong effect in the analysis of the *Integrity* category (KI_{12}, KI_{21}, KI_{32}), which in the global approach exhibit a causal or mixed character. This indicates that these factors change their character in the overall context compared to the considered other categories, thereby becoming causal factors for the emergence of factors belonging to other categories. The only factor that changes its character from causal to effect is KI_{31}, which in the global approach obtains values close to zero but with a negative sign. This means that for KI_{31}, the causes of its influence belong to other categories.

Regarding the position axis, an interesting fact is observed. This applies to factors with an effect character in the context of the Integrity category. Their significance increases in the global approach, whereas the opposite is true for factors with a causal character, as their value on the position axis decreases in the global approach. The reason for this interaction is the mutual influence of factors from outside the Integrity category, as well as factors from the considered category externally. This effect leads to an increase in the importance of effect factors but a decrease in the significance of causal factors.

6. SUMMARY

The article presents and analyzes the factors that constitute a set of criteria in the method of evaluating the adaptation of underground mining excavations. Through expert assessment, analyses were conducted for material categories, allowing for the identification of mutual cause-effect relationships between them. The DEMATEL method helped determine the character of the studied factors. In the cause-effect analysis, it was found that the criteria KU_{41} (*Historical documentation*) and KI_{11} (*Creation and operation*) have the most causal character, while the criterion KA_{22} (*Security Systems, Geometry, and Material*) from the authenticity category demonstrated the most significant effect character. The conducted cause-effect analysis showed that in analyzing the mutual influence of factors intended for evaluating the adaptation of underground mining excavations, KA_{31} (*Operation*) and KU_{11} (*Retaining the function*) have the greatest impact on the others, and both have a causal character.

In the analysis conducted for the *Integration* category, the criterion KI_{11} (*Creation and operation*) obtained the highest value, indicating its causal character. Additionally, it is positioned near the top of the criteria axis, indicating its significant influence on the others. On the other hand, the criterion KI_{32} (*Environmental hazards*) obtained the highest negative value, indicating its most significant effect character. Observing the position axis, it can be noted that criteria with causal character (such as KI_{22} – *Work safety*, which obtained the highest value on the position axis), including KI_{11}, have the greatest impact on the other factors.

The proposed scope of research analysis, along with the adopted criteria, should serve as the basis not only for assessing the resources but also for assessing the cultural heritage, geodiversity, and their state of preservation. In the decision-making process regarding contemporary interventions in underground mining spaces, these analyses enable the development of a so-called master plan. The essence of this process is the adaptation of underground mining spaces to new uses, which requires adjusting them to the technical conditions stipulated by building regulations and standards that encompass spatial and material safety requirements. The substantive basis for developing a master plan is to consider the mutual relationships between anthropogenic interventions and the preservation of material and natural heritage. A necessary condition is a properly conducted evaluative analysis of underground material and natural heritage, with particular emphasis on the preservation of authenticity, uniqueness, the functions of the excavations, and integrity, while considering all aspects related to visual-perceptual reception. An inherent part of the master plan is the implementation of contemporary methods of architectural, mining, and conservation interventions as an integral component of the adaptive process.

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