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Exploring the visual impact from open pit mines applying eye movement analyses on mining landscape photographs

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ABSTRACT

Mining landscapes have been widely acknowledged to be perceptually intrusive. Yet, the way visual attention of actual observers is affected by such landscapes has not been subjected to objective examination until the present time. In this study, an eye tracking experiment is utilized for the first time in the surface mining domain to explore the effect of the changes in open pit mine positioning and size upon observers' gaze patterns by utilizing eye tracking metrics and attention heatmaps. Statistical tests are also applied and both changes have been shown to significantly modulate the excavated surface's eye-catching properties, importance and observability.

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1. Introduction

Surface mining activities induce major alteration into the landscape [1–3,6] and high visual nuisance [4]. The observation of a mining landscape is associated with a number of factors affecting the visual impacts with respect to the human visual field. More specifically, the position (placement) and the representation rate (apparent size) of a quarry within an observer's visual field have been shown to influence the visual impression/preferences of a mining landscape [e.g. 7, 8, 9].

Basic premise for this research study is that the presence of certain landscape characteristics (e.g. mining features, built-up areas) significantly affect the visual preferences of the assessed landscapes [10]. Besides, research in mining landscapes, in particular, provides the potentiality to further proceed to negative evaluation judgments since such landscapes are broadly considered unpleasant [11]. In general, visual effects from surface mining activities are widely acknowledged. These effects are gradually encompassed in the environmental/landscape agenda of the European legislation [12,13], and are currently considered in the scientific research [4]. Nevertheless, the related scientific research and the legislative norms lack a proper objective and quantitative exploration of factors and variables contributing to the visual nuisance [4] utilizing experimental procedures that incorporate the visual experience of actual observers. *Eye tracking* techniques seem very promising for filling this apparent gap, 'objectifying' the subjective visual experience and impressions related to mining landscapes.

In order to specify the visual impact of landscapes shaped by mining projects, a step forward is to examine how such landscapes are visually perceived by observers. Many empirical research studies use photographs and photograph ranking for approaching the visual preferences of different landscapes – including mining/post-mining landscapes [e.g. 10]. However, only recently landscape perception has been subjected to more objective and rigorous scrutiny. Eye movement

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analysis and visualization techniques have been used to examine and measure people's observation of landscape in an objective way by recording the position and duration of gaze fixations, the velocity and direction of eye movements (saccades), and the blink rates while observing landscape photographs [14–17].

In the present research study, the influence of the changes in quarry positioning and size on observers' gaze patterns is explored by carrying out an eye tracking experiment. In broad terms, the gaze movements from a group of observers-participants are recorded and analyzed, while these participants observe mining landscape photographs. From these recorded and analyzed data: i) the way in which the photographs are visually explored (i.e. gaze patterns) and ii) the influence of the position and of the size of the represented open pits within these photographs occur. This paper presents the first – to the best of our knowledge – application of an eye tracking experimental procedure to objectively record, measure and analyze the visual exploration patterns of the observation of mining landscape scenes. In the following section, the effect of two crucial aspects pertaining to the visual attention of visual scenes in general is extended to encompass mining landscape scenes in particular.

2. The effect of position and size of open pit mines in landscape photographs

2.1. Position/placement effect

The position of an open pit mine is the first factor investigated in this paper. Several theoretical and empirical studies examine how the geometry and the placement of the constituent elements of a visual scene affect (i.e. intensify) the attention attraction of these elements.

The *Rule of Thirds* is a popular rule of thumb for determining the placement of the main element(s) or theme(s) in a photograph [18]. According to this rule, an image is divided into three equal horizontal and into three equal vertical sections forming a 3 × 3 grid. Where these – two horizontal and two vertical – lines dividing the image intersect, four positions or points of interest (PIs) occur. It is upon these PIs that a visually dominant element should be placed to be accentuated within a photograph and to further prompt a more balanced design and a more dynamic perception of this design [9,19]. Aside from these four accentuating or enhancing points (PI1, PI2, PI3, and PI4), the center point (PI0) is also considered an enhancing point [19] (Figure 1).

The placement of the represented landscapes' main themes/elements upon specific parts of the images or upon the PIs appears to perform a crucial role in observers' visual preferences. A significant preference towards pictorial arrangements possessing rightward (left-to-right) directionality has been shown to exist [20,21]. Such findings support the theory of both handedness and reading/writing habits effects on the aesthetic preferences of pictorial representations [21–23]. For instance, the finding that left-to-right readers/writers generally prefer images possessing rightward directionality and/or depicting the main theme on the right-hand side of the image, applies mainly to right-handers (dextrals) [e.g. 24, 25, 21, 26]. Correspondingly, right-to-left dextral readers present a preference for stimuli with a leftward directionality [21]. In general, right-handers exhibit a consistent pattern of preferring images possessing the same directionality as their reading/writing habits [21] and 'containing areas of greatest weight in their left portions, rather than the right' [26: 306]. For left-handers, this consistent pattern is not always explicit [e.g. 27].

Nevertheless, the preferences for landscape pictures *not* expressing directionality has *not* been explicitly shown to be modulated by these habits in particular [20], but tend to be influenced more by biological factors (i.e. handedness). As a result, no definite 'rules' underlying the viewing preferences and patterns are suggested when observing landscape photographs with no particular directionality. These 'rules' are rather case-sensitive, depending on a combination of characteristics (handedness and habits) of the observer and the content of the landscape photograph. In this sense, it would not be invalid to assume that in cases where dextral, left-to-right readers/ writers observe such landscapes, the main theme will tend to be noticed more rapidly when placed

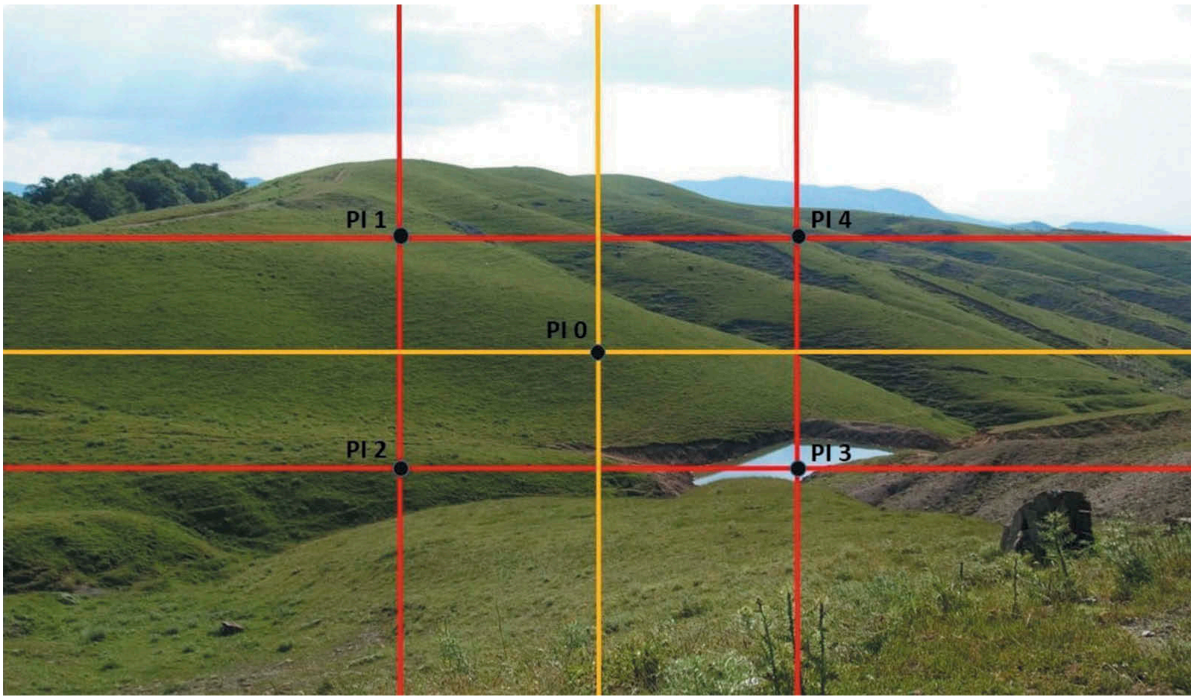

Figure 1. Grid formation according to the 'Rule of Thirds'. The intersection points of the primary grid (red lines) constitute the four points of interest (or of enhancement) – PI1: upper left, PI2: lower left, PI3: lower right, and PI4: upper right. PI0: center, occurring at the intersection of a secondary grid (yellow lines), constitutes the fifth point of interest. In this figure, the depicted pond – in PI3 – is expected to be enhanced.

in the left-hand-side of the picture. Yet, taking into consideration the evidence that scanning patterns proceed rightward from initial fixations [24,28], it is hard to predict what will be the implications of this evidence on the occurring patterns of attention and preferences. Even so, one possible assumption would be that this rightward scanning would induce the attention to be allocated less on the left-hand side of the image in comparison to cases where the main theme was already placed in the right-hand side of the image. In such cases, the initial detection of the main theme would have a little delay, but the attention would linger on it for long.

On the other hand, in their recent questionnaire-based research study, Svobodova et al. [9], showed that viewers exhibit a preference for left-hand side PIs in various landscape photographs. Moreover, it has been shown that 'placing positively perceived landscape elements at the [PIs] significantly increases positive evaluations of entire landscape scenes, while placing negatively perceived landscape elements according to the same rules makes negative evaluations [of entire landscape scenes] more negative' [9: 143].

Open pit mines and quarries are landscape elements that have been shown to significantly and negatively affect visual preferences for the assessed mining/post mining landscapes [8–10]. In cases where such elements (quarries) are placed upon the PIs, the assessment of the pertinent landscape photographs has been found to be more negatively evaluated, especially when the quarries where placed on PI1 and PI2 (left side of the photographs) [9]. These findings are very significant because they result from empirical research methods.

Nonetheless, the aforementioned methods are questionnaire-based and the derived data does not (objectively) record the gaze patterns of observers (e.g. whether the participants observed the PIs, how long they focused their gaze, how quickly they detected the point/theme of interest etc.). Eye tracking techniques can be utilized upon mining landscape photographs – i.e. visual scenes in which open pit mines tend to dominate the landscape – to record and analyze the eye movements of observers in an experimental and objective manner. Under such an eye tracking approach, it can be experimentally examined and shown: (i) whether the position of the represented open pits within the photograph (i.e. visual field) is a factor that affects the observers' viewing patterns and (ii) which position(s) or PI(s) tend(s) to be the most dominant in drawing the attention of observers. These two testable propositions are formulated in the following two more well-formed sub-hypotheses:

Hypothesis 1

Hypothesis 1a: The position (PI) where the represented open pit mine is 'placed', significantly/genuinely affects the participants' observation patterns (and, potentially, the visual preferences) regarding the (entire) mining landscape scene.

Hypothesis 1b: In cases where the represented open pit mine is 'placed' at the left side of the photographs, the visual attention is focused more intensively (and, hence, the visual preferences for this photograph are potentially further decreased).

2.2. Apparent size effect

The *representation rate* or the *apparent size* of any landscape element within the visual field is also a factor significantly influencing the perceptual processes and the occurring visual impressions. Mining landscapes, in particular, have been described and rated according to the relative size that the occurring quarries occupy within the visual field of a natural scene (landscape photograph) [7,8].

Thus, the quantitative composition of mining landscapes is deemed to be affecting the perceptual experience of such landscapes [7], whereas the percentage contribution of quarries is a compositional characteristic that can significantly influence the perceived aesthetic value and the preferences for mining/post-mining landscapes [8]. More precisely, for photographs in which excavated surfaces are not present, the observers positively evaluate the landscape; in cases where these surfaces are represented as non-dominant elements, the perceived beauty is reduced; when excavation surfaces are presented as dominant elements, the respective landscapes are evaluated even more negatively [8]. In addition, the effect of the apparent size of excavated surfaces has been also incorporated in the European Legislation (2002/272/EC decision) [13] and has been utilized by research studies under the approach of the *Lvi* (level of visual impact) method [2,29].

Since the increase of the apparent size of such elements has been empirically shown to diminish the visual preferences, or, inversely, to augment the visual impact of the overall impression of a visual scene (landscape), a necessity to experimentally inspect this association arises. Eye movement analyses can be applied to explore the effect of the varying apparent size of quarries on the human gaze patterns through an experimental procedure. Therefore, a rigorous eye tracking experiment can be carried out to show: (i) whether the apparent size of a represented quarry within photographs displayed on a computer monitor (approximating the visual field) is a factor that affects the respective viewing patterns and (ii) what is the relationship between the apparent size and the focus of human attention. From these two propositions, two sub-hypotheses are derived:

Hypothesis 2

Hypothesis 2a: The apparent size of the represented open pit mine, significantly/genuinely affects the participants' observation patterns (and, potentially, the visual preferences/impact) regarding the (entire) mining landscape scene.

Hypothesis 2b: In cases where the open pit mine is represented in a greater apparent size, the visual attention is focused more intensively (and, hence, the visual preferences for this photograph are potentially further decreased).

3. Methodology

3.1. Participants, visual stimuli and observation/viewing procedure

3.1.1. Participants

Forty participants-observers, 22 females and 18 males, between 19 and 52 years old, 35 right-handed, 3 left-handed and 2 both-handed, – chiefly undergraduate and postgraduate students of the National Technical University of Athens, and other members of the university community – voluntarily participated in this eye tracking experiment. They were mainly engineers (civil, rural, architectural, chemical, mining) or with a background in geo- and environmental sciences. The participants were informed in general terms about the experiment regarding the way the experimental apparatus functions and regarding the requirements for the orderly and effective experimental performance (expected duration of the experiment, importance for the participants to remain concentrated during the experiment). However, participants were not given any details about the aims for carrying out the experiment. Moreover, the use of mascara or eyelash extensions was forsaken, while participants wearing eyeglasses were asked to wear contact lenses instead for the increase of measurement accuracy and for avoiding erroneous or non-existing eye movement recordings [30].

3.1.2. Visual stimuli

Twenty photographs representing almost the same mining landscape constitute the visual stimuli for the experiment. The photographs were captured in a manner that certain requirements were satisfied, contributing to the aims of the research. So, photographs of the Merenta quarry (Markopoulo Mesogaias municipality, Attica, Greece) were taken using a DSLR (Digital Single-Reflex Lens) camera with a 12.3 megapixels sensor. A tripod was utilized to ensure photograph capture stability and a constant shot height of 170cm – approximating the human viewing height. The viewing point is located northwest of the Merenta quarry, so the photographs represent the northwestern aspect of the quarry.

The differences among the photographs refer to the position of the represented quarry, the position of the horizon/sky and the presence/absence of clouds in the sky. More specifically, the photographs were captured in a manner that the represented quarry was depicted upon the 5 positions (PI0, PI1, PI2, PI3, PI4, and PI5) within the 'same' mining landscape. In addition, the photographs were captured with two different focal lengths, 18mm and 24mm, for the quarry to be represented in a different apparent size. From the combination of 5 different positions and 2 different focal lengths, a subset of 10 photographs was 'created'. These 10 photographs, having been captured under actual (natural) lighting/atmospheric conditions and under an overcast sky (the day and hour of capture), were processed for the clouds to be removed. So, ten more photographs were created in which the sky was clear. In total, the photographs been utilized as visual stimuli for this experiment were 20 (Table 1 and Figure 2). Finally, the photographs were presented to the participants according to the order appearing in the lower row of Table 1 for reasons described in §3.3.

3.2. Laboratory/experimental apparatus and recording procedure

3.2.1. Laboratory/experimental apparatus and recording procedure

The utilized experimental equipment consists of the eye tracking system – Viewpoint Eye Tracker® by Arrington Research, a PC and two computer monitors supported by two separate GPUs (Graphic Processing Units). The display monitor used for conducting the eye tracking experiment was a 19-inch one with a resolution of 1280 × 1024 pixels. During the experiment, the participants were seated in such a position so that the distance between their eyes and the display monitor was 60 cm. The system's (gaze recording) sampling rate equals to 60 Hz (gaze records every 16.67 ms), while the recording system's spatial accuracy lies between 0.25–1.00^{o} of the visual arc. Further information about eye tracking equipment and calibration process can be found in previous studies [31,32].

Table 1. Classification of the experiment's visual stimuli (photographs) according to the position of the represented open pit mine, the focal length of photograph shots and the 'status'/conditions of the sky.

Actual lighting conditions/cloud presence										Processed sky/cloud absence									
Focal length: 18mm					Focal length: 24mm					Focal length: 18mm					Focal length: 24mm				
P0	P1	P2	P3	P4	P0	P1	P2	P3	P4	P0	P1	P2	P3	P4	P0	P1	P2	P3	P4
3	18	8	17	10	9	16	15	20	6	1	13	5	7	4	19	11	2	14	12

Note 1: the numbering/order of photographs' presentation is explained in §4.4.2. Note 2: P0: Center, P1: Upper Left, P2: Lower Left, P3: Lower Right, P4: Upper Right.

Figure 2. Visual stimuli (landscape photographs) utilized for the eye tracking experiment. In the top two rows, the photographs are presented under actual lighting and cloud cover conditions, while in the photographs in the two bottom rows the sky has been processed so as to be clear. Left to right, the placement of the open pit is changing, while top to bottom the focal length is changing. The numbering and categorization of photographs is in accordance with and results from Table 1.

3.2.2. Selection of experimental conditions

The eye tracking experiment was conducted at the Laboratory of Cartography of the National Technical University of Athens (NTUA). This experiment was chosen to be carried out under controlled conditions so as to: i) avoid distractions present in *in situ* research studies in actual conditions (e.g. noise, moving objects, changes in lighting conditions etc.) and ii) provide the capability for manipulating the (variables of the) visual stimuli at will. For the laboratory conditions to be prioritised against the real conditions, landscape photographs are assumed to constitute valid/reliable substitutes of actual conditions [33–36].

3.3. Viewing procedure

For the requirements of the eye tracking experimental procedure, the 20 mining landscapes were displayed for 10 seconds each. The 20 photographs were displayed in such an order that the modification of the variables under study was not directly perceivable – since this would systematically affect the participants' observation patterns. For instance, if the sole element changing during the transition from the one photograph to the next one was the modified sky conditions, the participants might have focused their attention towards these changing regions.

In addition, a 16-dot (auto)calibration was performed to ensure the accurate coordinate's transformation from the participants' eye reference system to the entire monitor's reference system, while a validation procedure was also performed to ensure that only the recordings of participants exhibiting adequate gaze spatial accuracy would be ultimately selected for further analysis, following the method described by Krassanakis [37],and Krassanakis et al. [32]. The procedure was repeated in cases where the calibration was rated unsuccessful, while the analysis was based only on the valid and adequately accurate datasets (the datasets of only 40 of the 68 observers initially participating the experiment were selected for further analysis).

The participants were asked to attentively observe these photographs under *free-viewing* conditions. This means that the participants were *not* to perform any specific *cognitive task* (e.g. to spot the edges of the quarry) but rather to freely observe the photographs. This free-viewing process was chosen primarily so as to simulate the way people observe landscapes in real life, i.e. without any specific purpose (cognitive task) [16,38]. Moreover, the participants had neither observed the particular photographs before, nor knew anything else other than that they would participate in a research study whereby their gaze movements would be recorded while observing some landscape photographs.

Before initiating the experimental procedure and before placing and 'stabilizing' the participants in their seats, all participants were given the same instructions regarding the successful realization of the procedure.[1] After the completion of the eye tracking test, the participants provided some information for the further utilization of the eye tracking recordings.

3.4. Eye movement data processing and analysis

The initial raw data were transformed into main eye tracking metrics, i.e. *fixations* and *saccades* using *OGAMA (Open Gaze and Mouse Analyzer) (5.0)*, an open source software designed to import and analyze eye movements [39]. Fixations correspond to the relatively fixed gaze positions while saccades are the eye transition movements connecting these positions [40,5]. The further analysis of gaze recordings is based on the computation of metrics derived by fixations and/or saccades [40,41], as well as on several visualization techniques which jointly serve in the understanding of how mining landscapes are visually explored and perceived during the (free-) viewing of respective photographs [16,17,40].

3.4.1. Qualitative analysis – attention allocation visualization

The visual attention allocation of all 40 participants-observers for each landscape photograph was visualized in the OGAMA software by producing attention heatmaps, that is aggregate visualizations of the observation patterns, based on fixation duration. Such types of heatmaps are appropriate since they not only reveal the areas being attended, but they are also robust indicators of the level of cognitive processing required [42].

3.4.2. Quantitative analysis – eye tracking metrics' calculation

Three eye tracking metrics (ETMs) were employed towards quantitatively investigating the visual effect of the quarry within the landscape under study. In order to utilize these metrics, the excavated surface (quarry) was initially delineated as an Area of Interest (AOI) in OGAMA. These metrics, been suggested and utilized by Misthos et al. [43], are the following: *(i) Mean Time to First Fixation (MTFF) within the quarry, (ii)Mean Fixation Time Ratio (MFTR) within the quarry and (iii) Mean Number of Fixations Ratio (MNFR) within the quarry.*

The mean time required for the observers to make the first fixation (MTFF) within the quarry constitutes the first metric for quantitative analysis. Faster times imply that the AOI-element has better attention-catching properties [40,45]. Hence, if there are photographs for which the quarry is detected much faster, this probably means that their elements' composition is such that renders the quarry more observable.

Mean Fixation Time Ratio is related to the metric of gaze (fixation) duration per AOI; this metric suggests that for longer durations, viewers experience greater difficulty in extracting information from the AOI-element, or that they find it somehow more engaging [40–42]. Thus, MFTR indicates the degree to which the quarry-AOI is more engaging or difficult to be processed when compared to the totality of the photograph. With MFTR, the fixation duration within the quarry is compared to the fixation duration all over the photograph. It is calculated as follows:

$$MFTR(\%) = \frac{Mean\ Fixation\ Time\ at\ AOI}{Complete\ Mean\ Fixation\ Time} * 100 \tag{1}$$

Mean Number of Fixations Ratio pertains to the metric of fixations per AOI; this metric signifies that for higher values the AOI is more noticeable or more important to the observer, compared to other AOIs [40,41]. More specifically, MNFR indicates the degree to which the quarry-AOI is more noticeable than the totality of the photograph. With MNFR, the number of fixations within the quarry is compared to the number of fixations all over the photograph. It is calculated as follows:

$$MNFR(\%) = \frac{Mean\ Number\ of\ Fixations\ at\ AOI}{Complete\ Mean\ Number\ of\ Fixations} * 100 \tag{2}$$

3.4.3. Statistical analysis

The two variables tested are the relative position of the quarry and the apparent size of the quarry within the photographs. The three ETMs (see previous section) can be utilized to find out whether there is a statistical association among these metrics and these variables. More precisely, we investigate whether the values for the three ETMs vary as the position and as the apparent size of the quarry vary.

To this end, a comparison of means among the different relative positions and apparent sizes of the quarry for the three derived ETMs was carried out. As a rule, ETMs do not follow a normal distribution [16,30]. This was also demonstrated by performing the Kolmogorov-Smirnov /Shapiro-Wilk tests of normality on the three ETMs. Hence, a Kruskal-Wallis test (k samples) for non-parametric data was applied in order to test whether the distribution of the ETMs and their means, based on ranks, significantly differ across the different relative positions and apparent sizes of the quarry.

4. Results and discussion

4.1. Attention maps' qualitative analysis

The produced attention maps (heatmaps) reveal that the visual attention of the participants is heavily focused on regions within the quarry-AOI for all 20 mining landscape photographs (Figure 3). Nevertheless, there are quantitative differences in the visual attention distribution as the position of the quarry changes. When the quarry was placed at the lower left quadrant of the photograph, the gaze patterns were much more clustered than in any other case, whereas significantly more dispersed patterns occurred when the quarry was in the lower right and upper right quadrants of the photographs, respectively (i.e. right and center attention maps). In general, the participants' visual attention was mostly focused in the excavated surface when the latter was positioned at the lower left quadrant or at the center of the photographs.

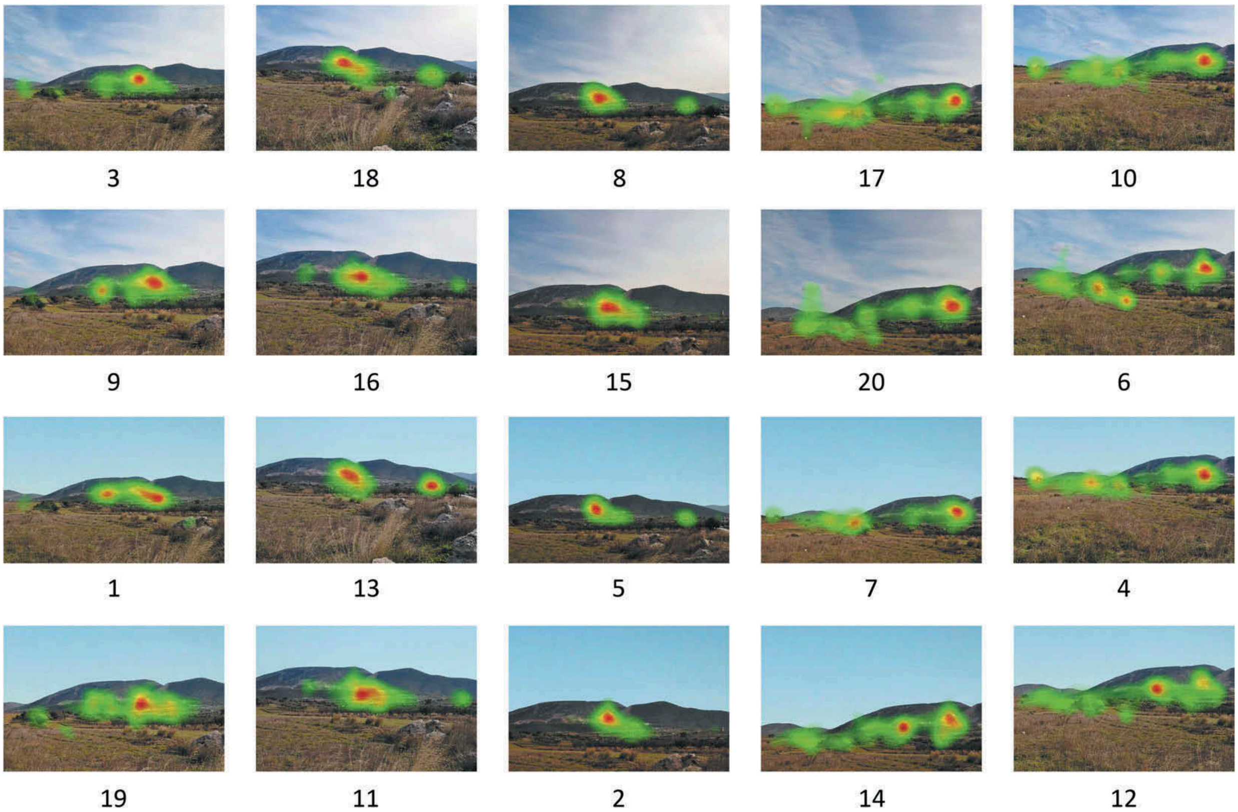

Figure 3. Attention heatmaps of the 40 participants for the 20 mining landscape photographs. The visual attention is focused mainly on regions within the represented quarry in all 20 photographs.

Additionally, the visual attention was more intensively allocated within the quarry when its relative (apparent) size was increased. As for the effect of cloudiness and lighting conditions, it is shown that the produced attention patterns are rather similar when comparing pairs of the same photographs with an overcast and a clear sky (e.g. heatmap 18 compared with 13, 16 with 11 etc.).

4.2. Eye tracking metrics' quantitative and statistical analysis

4.2.1. Descriptive statistics

By the calculation of the descriptive statistics (min/max and arithmetic means) for the three ETMs per quarry position and size (Table 2), several results emerge. In total, the fixations within the quarry are comparatively much greater in number and duration than those occurring in the rest of the photographs, considering the small area percentage of the quarry (less than 3% in any case). More analytically, considering:

- the relative position of the quarry:
  - MTFF is always lower than 2500 ms (irrespectively of the quarry's apparent size) when the quarry is positioned at the lower left quadrant or at the center of the photographs. Contrariwise, the MTFF ranges between ~3000–3700 ms when the quarry is placed at the right-hand side of the photographs. So, the quarry is spotted more quickly by the observers when placed at the lower left quadrant or at the center of the photographs, while observers delay to execute their first fixation in the quarry when the quarry is placed at the right-hand side of the photographs.
  - MFTR and MNFR get their highest value when the quarry is positioned at the lower left quadrant or at the center of the photographs and their lowest values when the quarry is

Table 2. Descriptive Statistics for the three ETMs.

Position of Quarry	Relative Size of Quarry- (%)		N	Minimum	Maximum	Mean
Center	1.74	MTFF (ms)	73	0.00	8616.00	2244.78
		MFTR (%)	80	0.00	64.25	15.26
		MNFR (%)	80	0.00	55.56	14.15
	2.88	MTFF (ms)	70	0.00	9448.00	2431.11
		MFTR (%)	80	0.00	79.69	16.22
		MNFR (%)	80	0.00	76.47	16.21
Upper Left	1.74	MTFF (ms)	54	303.00	9687.00	3465.50
		MFTR (%)	80	0.00	73.49	10.73
		MNFR (%)	80	0.00	62.07	9.67
	2.88	MTFF (ms)	63	0.00	9154.00	2329.51
		MFTR (%)	80	0.00	74.06	15.25
		MNFR (%)	80	0.00	61.11	14.23
Lower Left	1.74	MTFF (ms)	68	0.00	9169.00	2291.24
		MFTR (%)	80	0.00	83.02	14.48
		MNFR (%)	80	0.00	61.11	13.16
	2.88	MTFF (ms)	75	0.00	9789.00	1855.12
		MFTR (%)	80	0.00	56.66	20.03
		MNFR (%)	80	0.00	58.33	18.64
Lower Right	1.74	MTFF (ms)	57	243.00	8990.00	3636.21
		MFTR (%)	80	0.00	84.15	11.16
		MNFR (%)	80	0.00	63.16	10.09
	2.88	MTFF (ms)	66	0.00	9207.00	2915.38
		MFTR (%)	80	0.00	63.67	15.00
		MNFR (%)	80	0.00	50.00	13.84
Upper Right	1.74	MTFF (ms)	58	387.00	9274.00	3743.97
		MFTR (%)	80	0.00	80.66	11.64
		MNFR (%)	80	0.00	60.00	9.93
	2.88	MTFF (ms)	64	26.00	9194.00	3240.64
		MFTR (%)	80	0.00	72.57	15.03
		MNFR (%)	80	0.00	66.67	13.74

placed at the right-hand side of the photographs. Since the visual attention is more intensively allocated in the quarry when placed in the first two positions, it is in these two positions that is rendered more important, noticeable, or more engaging to the observer.

- the apparent size of the quarry:
  - MTFF is reduced by ~400–700 ms when the apparent size of the quarry is increased, nearly for every placement of the quarry. This means that the eye-catching potential of the quarry is augmented as its apparent size increases. This does not apply for the center position (a 200 ms increase in the MTFF is observed), possibly because the MTFF is already adequately low.
  - MFTR and MNFR values rise when the quarry's size is increased – irrespectively of the quarry's positioning. However, the most significant raise is noted where the quarry is represented at the left-hand side of the photographs (~5% increase).

It should be noted that the number of observations (N) is reduced (in Table 2, and in Tables 3 and 4 in the next sub-section) for the MTFF metric because there are cases that participants did not observe the quarry-AOI at all.

4.2.2. Non-parametric tests

4.2.2.1. Relative position. The Kruskal-Wallis test indicates a significant difference in all three ETMs (MTFF, MFTR and MNFR) in the two photographs where the quarry is positioned at the lower left or at the central part of the photographs compared to the other three photograph cases ($p < 0.01$) (Table 3). Thus, it emerges that the eye-catching properties, the importance and the

Table 3. Results of the Kruskal-Wallis test per ETM: The mean ranks for the three ETMs are significantly different across differing placements of the quarry.

Position of Quarry		N	Mean Rank	P
MTFF (ms)	Center	143	285.15	0.000
	Upper Left	117	334.02	0.000
	Lower Left	143	257.80	0.000
	Lower Right	123	375.87	0.000
	Upper Right	122	387.88	0.000
	Total	648		
MFTR (%)	Center	160	439.87	0.002
	Upper Left	160	364.28	0.002
	Lower Left	160	444.72	0.002
	Lower Right	160	378.97	0.002
	Upper Right	160	374.66	0.002
	Total	800		
MNFR (%)	Center	160	446.25	0.000
	Upper Left	160	363.90	0.000
	Lower Left	160	450.06	0.000
	Lower Right	160	376.27	0.000
	Upper Right	160	366.02	0.000
	Total	800		

observability of an excavated surface are augmented in a statistically significant way (i.e. genuinely) when the excavated surface is placed in the lower left or at the central part of landscape photographs compared to the cases where this surface is on the right-hand side of the image.

4.2.2.2. Apparent size. The Kruskal-Wallis test indicates a significant difference in all three ETMs in the two photographs where the quarry is represented in a different apparent size ($p < 0.01$) (Table 4). For a greater apparent size, MTFF is dropping, while MFTR and MNFR are rising. Thus, the eye-catching properties, the importance and the observability of a represented quarry are increased in a statistically significant way when its apparent size is also increased.

5. Discussion

5.1. Verification/corroboration of the hypotheses

5.1.1. Hypothesis 1

5.1.1.1. Hypothesis 1a. Our experimental research study has shown that the viewing patterns are indeed influenced by the position (PI) where the quarry is placed. The visual attention allocation is differentiated between different quarry positions, as it emerges from the heatmaps' examination and from the ETMs' arithmetic means. The statistical analysis' results ensure that the differences in the focus of visual attention are genuinely 'caused' by the differences in the open pit placement within the photographs (landscape scenes).

Table 4. Results of the Kruskal-Wallis test per ETM: The mean ranks for the three ETMs are significantly different across differing apparent sizes of the quarry.

Relative Size of Quarry (%)		N	Mean Rank	P
MTFF (ms)	1.74	310	345.20	0.006
	2.88	338	305.52	0.006
	Total	648		
MFTR (%)	1.74	400	369.25	0.000
	2.88	400	431.76	0.000
	Total	800		
MNFR (%)	1.74	400	361.97	0.000
	2.88	400	439.03	0.000
	Total	800		

5.1.1.2. Hypothesis 1b. This hypothesis is partly corroborated by the eye tracking experimentation and statistical analysis. The attention is indeed focused the least in the cases where the open pit mine is placed at the right-hand side of the photographs (PI3 & PI4). However, the attention is not attracted that intensively at the upper-left quadrant (PI1), even though all the respective ETMs get higher values compared to the previous two cases (PI3 & PI4). The attention is more heavily allocated at the center (PIO) and at the lower-left quadrant (PI1) of the mining landscape scene.

These findings partly accord with the pertinent literature. Since reading/writing habits have been found to influence the observers' aesthetic/visual preferences [21–23], it follows that given our culture and language (Greek) the right-hand side of the image should attract the attention less intensively. While this is true in our experimental research, the fact that the landscape photographs utilized do not possess directionality makes the association with the literature more complicated; according to De Agostini et al. [20], the reading/writing habits do not modulate preferences for landscape scenes not involving directionality. In such cases, the handedness appears to play an important role, with right-handed viewers to express a rightward preference irrespective of their reading habits [21,23].

Since the participants in our experiment where by 87.5% right-handed, one would expect the visual attention to be allocated more intensively at the right-hand side of the photographs. The rightward scanning from initial fixations [24,28] could induce the attention to be allocated at the right parts of the images. Nevertheless, Svobodova et al. [9], have revealed – based on questionnaires – a significant preference for landscape scenes where the main themes were positioned upon PIs at the left-hand side of the photographs. In our research study, this finding has been partly supported by the qualitative and quantitative results from the eye-tracking experimental approach. While the lower-left position (PI2) is the most dominant position, the center position also serves in substantially attracting the attention within the quarry; contrariwise, the upper-left position – the most dominant position in the study of Svobodova et al. [9], – has not been experimentally shown to intensify that much the attention capturing.

5.1.2. Hypothesis 2

5.1.2.1. Hypothesis 2a. The viewing patterns have been shown to be indeed influenced by the apparent size of the excavated area in almost all PIs. The visual attention allocation is differentiated between the two relative sizes of the represented quarry, as it emerges from the heatmaps' and from the ETMs' arithmetic means comparisons. The statistical analysis' results warrant that the differences in the focus of visual attention are genuinely 'caused' by the differences in the open pit's apparent size within the mining landscape scenes.

5.1.2.2. Hypothesis 2b. This sub-hypothesis is corroborated in all positions except one (center – PI0) by the eye tracking experimentation and statistical analysis. The attention is indeed focused more intensively when the open pit mine is represented in a larger apparent size. The arithmetic means of the ETMs provide this information in an explicit manner: when the quarry's size is increased, MFTR and MNFR values always rise, whereas MTFF is almost always dropping; only for the center position (PI0), the mean time required for the observers to make the first fixation (MTTF) slightly rises with the increase of the open pit mine's size.

The research finding that there is a shift in visual attention allocation from a lesser to a greater apparent size of an excavated surface constitutes the experimental base for comprehending the perceptual behavior and observation patterns underlying the evaluation level of mining landscapes. Svobodova et al. [8], have indicated that the quarries' apparent size augmentation is accompanied by a reduction of the perceived beauty or the aesthetic value of a mining/post/mining landscape. This diminution of the visual preferences or the amplification of the visual impact could occur, in the light of our findings, due to the fact that the eye-catching properties, the importance and the observability of an excavated surface are augmented as the quarry's apparent size rises. On the other hand, this experimental and quantitative approach scientifically supports the choice to incorporate the quarries' apparent size in the existing European legislation [13]. In addition, these first findings signify that further experimental work is required in order to specify and parameterize the criteria for assessing the visual impact from open pit mines in an impartial and scientific manner.

5.2. Significance of the research

5.2.1. Significance of the research findings for the mining sector/domain

In several everyday life cases, the local material conditions provide us with a relatively 'fixed' landscape frame (views from interior spaces through windows, views through the 'cityscape', views while moving inside vehicles). In many of such cases, lots of people get involved (front windows in airports' waiting rooms, highways etc.). Being able to specify beforehand at which positions of the visual field a quarry can draw more rapidly and more intensively actual observers' attention is an important piece of knowledge which can scientifically inform decisions. These decisions may be related to the open pit mine design choices, or even the more general spatial planning.

The visual attention attraction is significantly modulated by the apparent size of the quarry. Moreover, the quarry's apparent size is related to the viewing position proximity from the quarry area. Since there is experimental evidence that for greater apparent sizes the quarry was more noticeable and engaged the attention, the same applies the nearest the viewing position is to the quarry. This piece of evidence should also inform the decisions for mining projects and landscape/land use design for the mining area to be the least possible observable and 'perceptually intruding'. Viewpoint locations from which the excavated surface gets a large apparent size should be avoided for sensitive (in terms of visual impact) land uses (e.g. archaeological or touristic sites).

5.2.2. Significance of the eye tracking methodology for the mining sector/domain

The general approach of this research paper is novel and important in methodological terms. 'Mapping' and quantifying the allocation of the visual attention of actual observers regarding (the position and apparent size of) quarries is a crucial step for understanding and modelling the visual perception of mining landscapes. Furthermore, delineating the visual perception of mining landscapes may provide the basis towards predicting their visual impact: 'the visual impact of an object is reduced when its visual perception decreases' [15]. Therefore, eye tracking is a novel and useful methodology for studying one of the main problems related to the mining activities, i.e. visual nuisance. In contrast to other methods and techniques which focus solely either on the objective variables of the stimuli (e.g. chromatic contrast, landscape composition etc.) or on the subjective impressions of the observers (e.g. through questionnaire-based surveys), eye tracking enables the *objective recording and measurement of what is subjectively perceived by actual observers*. This inherent but neglected and unexploited strength of eye tracking for the mining domain is promoted and utilized through this paper.

6. Conclusion and future research

Investigating how people observe mining landscapes in practice is a crucial and unexplored research domain with potential implications on the surface mining design and landscape/land use planning. This research study is the first – to the best of our knowledge – to experimentally explore actual observers' viewing patterns and behaviors while free-viewing mining landscape photographs utilizing eye tracking techniques.

The visual perception and impression of mining landscapes is deemed to be modulated by several variables or factors. In this paper, we explored the influence of the relative positioning and apparent size of open pit mines upon the visual attention allocation – within appropriately captured mining landscape photographs. The eye movement visualization and analysis coupled with statistical analysis showed that there is a genuine and significant effect of these two variables upon the 40 participants' patterns of visual attention. One of the most significant findings from this experimental methodology and analysis is that the two PIs at the right-hand side of the photographs (PI3 & PI4) indeed render the quarry less observable and less engaging or important to the viewer. In addition, the decrease of the apparent size of the excavated surface leads to a less clustered visual attention focus within the quarry, further connoting that the quarry is visually perceived as a less dominant element within a given mining landscape scene when its apparent size is dropping.

The aforementioned findings could be of practical significance in supporting decisions regarding the future surface mining design and landscape planning. In addition, this research study is methodologically sound and novel because eye tracking, a method which objectively records the subjective gaze patterns of actual observers while free-viewing mining landscape photographs, is utilized for the first time in the surface mining domain.

Visual perception and attention constitute the necessary conditions for further addressing and assessing the visual impact or nuisance in mining landscapes. This eye tracking approach has concentrated on unveiling the viewing patterns while observing such landscapes. Yet, much work is required to explore and comprehend the relationship between perception and evaluation – if there is really any –, by coupling objective (eye tracking) and subjective (e.g. qualitative surveys) methods. Moreover, the three specific fixation-related ETMs were utilized since they appear relative or/and have been already utilized in the relative literature. Other saccade-related metrics or mixed metrics (fixation/saccade-related) can be used to better approximate the particularities of mining landscapes. The development of an aggregate indicator which properly integrates pertinent ETMs as well as the involvement of expert judgment procedures [e.g. 44] could serve in evaluating mining landscapes in terms of their visual nuisance.

Note

1. These instructions were based on the instructions adduced by Dupont et al. [17: 72–73].

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No potential conflict of interest was reported by the authors.

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