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Legwaila, I.A., Lange, E. orcid.org/0000-0002-2917-697X and Cripps, J. (2019) Assessing the effects of quarry treatment options on the attractiveness of reclaimed limestone quarries using 3D-visualizations. International Journal of Mining, Reclamation and Environment, 34 (3). pp. 179-197. ISSN 1748-0930

https://doi.org/10.1080/17480930.2018.1561387

Published in: International Journal of Mining, Reclamation and Environment
https://doi.org/10.1080/17480930.2018.1561387

Assessing the effects of quarry treatment options on the attractiveness of reclaimed limestone quarries using 3D-visualizations

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This research was funded by
The Botswana University of Agriculture and Natural Resources
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Botswana

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Published in: International Journal of Mining Reclamation and Environment
https://doi.org/10.1080/17480930.2018.1561387

Abstract

This study investigated the effect of different limestone quarry reclamation treatment options on people's perception of reclaimed limestone quarries. Ten different combinations of treatment methods and after-care for reclaiming quarries were simulated from which fifty still images were captured along a transect at five different distances from 50m to 6400m. The attractiveness and different landscape characteristics were rated at the University of Sheffield by seventy students with different academic backgrounds.

Highly visible rock was least preferred whereas landscapes that contained water and trees received the highest preference ratings. The methodology and overall findings would be applicable to landscape quality assessment and reclamation in other settings

Keywords

Distance effect; 3D-visualization; backfilling; bench-planting; restoration blasting.

Published in: International Journal of Mining Reclamation and Environment
https://doi.org/10.1080/17480930.2018.1561387

1. Introduction

1. Limestone quarrying and reclamation

Limestone is a mineral product for which there is a high demand in England, as well as in other countries (British Geological Survey, 2009; Verney, 1976). It is used mainly for construction purposes, including road building and concrete aggregate, but it also has other uses such a raw material for smelting flux, cement manufacturing and in the chemical industry (Tandy, 1975).

As pointed out by Rabinowitz and Coughlin (1970), Lange et al. (2008) and others, people tend to dislike particular anthropogenic elements or features introduced into natural landscapes. Operating quarries are not an exception to this and it is probably one of the reasons that, as noted by Bell (1999), there is usually public antipathy towards development of new quarries or extension of existing ones. Reclamation however, provides the potential to generate positive reactions. With appropriate design and execution it can provide new opportunities for different land-uses as well enhancing environmental quality in an area and, most importantly, the visual quality of the overall landscape. Furthermore, as quarry faces usually have cracks and crevices that may be colonised by a variety of plant and animal species. As such they can support valuable ecosystems which because of their inaccessibility provide undisturbed plant and wildlife habitats (Baczynska et al., 2017[b]; Yundt et al., 2002)

Different quarry reclamation techniques have been developed over time (see Cripps et al., 2007 and Legwaila et al., 2015). They are designed to reduce the negative visual impacts of quarrying. Some of these are applied retrospectively, but better quality and greater efficiency are achieved if they are incorporated into the quarrying operations. In the case of limestone quarries in England, the most commonly applied methods include those listed in Table 1. These may be used singly or in combination with each other or other methods.

Unrestored and abandoned quarries will undergo a process of natural recovery in which, as Legwaila and Lange (2015) explain, re-vegetation relies on the presence of seeds and roots in the soils or on being transported from adjacent land by natural processes. Depending on the situation and environment processes in vegetation, succession may take several decades. On the other hand, several studies, including those by Vojar, et al. (2016), Dolezalova, et al. (2012), Tropek, et al. (2012)' Hendrychová (2008) and Cilek (2006), have concluded that quarried sites which have been left to natural recovery produce landscapes of high diversity and aesthetic value.

It is essential to understand how reclaimed quarry landscapes affect people's perception of the visual quality in order to best plan, design, develop and manage the landscapes for public enjoyment (Arthur et al., 1977). According to Simpson (1979, p330) such understanding can "enable strong rationale for visual resource management". It can provide guidance to reclamation specialists and policy makers in their application of the environmental assessment tools (EIA and LVIA) on how people may perceive proposed limestone quarry reclamation schemes.

This study seeks to assess how different reclamation techniques and distance affect the attractiveness of reclaimed limestone quarry landscapes with the aim to:

1. Identify reclamation techniques, quarry landscape features and characteristics that enhance the reclaimed landscapes.

2. Explore how distance affects attractiveness of reclaimed limestone quarry landscapes and contribute to theory on the relationship of distance and attractiveness of landscapes.

3. Explore how different groups of people perceive attractiveness in reclaimed limestone quarry landscapes and contribute to theory on the subject of differences between participant groups in rating landscapes.

4. Provide guidance to quarry reclamation practitioners on valued quarry landscape qualities.

This research aims to improve the understanding of the relationship between reclaimed limestone quarry landscapes and people's perceptions of their visual quality in order to deliver enhanced aesthetic appeal through the use of more appropriate design and management in reclamation projects (Baczynska et al., 2018; Baczynska et al., 2017ab; 1989; Kaplan, 1988; Sadler & Carlson, 1982).

1.2. Significance of visual quality

Lange and Legwaila (2012) point out that visual quality is a public resource that needs planning for, and requires continuous management to ensure its sustainability. In terms of quarry restoration, this is possible only if there is an appreciation of what constitutes visual quality in reclaimed quarry landscapes. This understanding can help those responsible for quarry reclamation to incorporate features into schemes that enhance the visual qualities of the reclaimed quarry landscape (Simpson, 1979).

Most quarry sites that require reclamation are in rural areas. Although there are many quarries in urban settings, it is rather common for these to be reclaimed as development sites or for recreational uses in which aesthetic considerations are of secondary importance. Cripps and Czerewko (2010), provide some examples of the treatment and conservation value of urban quarries. The use of the countryside for leisure activities (Baczynska et al., 2018; Baczynska et al., 2017ab) gives rise to pressure for rural quarries to be restored. As explained by Cripps *et al*. (2007) the combination of hard rocks in close proximity to urban areas gives rise to upland areas that may be designated for their aesthetic and landscape value. In the UK many of these sites exist within designated areas, including National Parks, Areas of Outstanding Natural Beauty (AONB), and Sites of Significant Scientific Interest, (SSSI) (Ramos and Panagopoulos, 2006; British Geological Survey, 2009). It is likely that provision for access, either physical or visual, will be required in the case of locating quarries in or near designated sites and tracts of land. Thus, it is necessary to consider what the public will experience from different vantage points, both near and far when planning quarry restoration or reclamation schemes. Vantage points should be located at representative positions in the landscape where people can see the landscape from natural positions; i.e. sitting or standing (Palmer and Hoffman, 2001).

2. Methods

2.1. Research Strategy

This study was based on a hypothetical limestone quarry thus avoiding bias towards a specific site. A systematic, perception based method (Dobbie and Green, 2012; Green, 2010) was used to assess reclaimed quarry landscape visualizations (Bishop et al., 2001; Muhar, 2001; Wergles & Muhar, 2009). Despite some limitations in developing realistic dynamic models, Ervin (2001) argues that visualizations of high quality should be developed to best compare alternatives and judge visual quality while accepting the limitations of the technologies involved. The visualizations should be representative, accurate, visually clear, interesting and legitimate (Sheppard, 1989)

The use of a relatively simple method for determining and rating the attractiveness of different landscape features in an overall landscape scene is developed. In this study, the participants rated the completed scenarios with fully-grown vegetation in the summer season, but the methodology could be easily adapted to evaluate reclamation schemes at different stages of development and at different seasons, with varying lighting conditions and vegetation attributes.

The overall research strategy involved survey of participants to establish their views on the attractiveness of landscapes depicted in ten different reclaimed quarry landscape scenarios. These were designed to represent three different quarry reclamation treatments, respectively Backfilling, Restoration blasting and Bench planting. These were combined with three different post-quarrying land uses, namely Agriculture, Nature conservation, and Woodland (Table 2). There are many different after-uses that land degraded by mineral extraction can be put to (Baczynska et al., 2018; Baczynska et al., 2017ab; Legwaila and Lange, 2015). The three most common after-uses are agriculture, nature conservation and forestry or woodland (Department of Environment, 1989). The choice of any after-use will depend mainly on the type of mineral and method of extraction. Other factors that need to be considered include the final depth of excavation and its relation to the water table, the amount of waste material, availability and quality of topsoil, local terrain, altitude, climate and presence of wildlife habitats, cultural background of the site, hydrology, land ownership, adjacent land uses, land stability, geophysical structure of the site and socio-economic factors (Department of Environment, 1989; Gardner, 2001; Land-Use-Consultants, 1992a; Moffat & McNeill, 1994). According to the Countryside Commission (1993, p36), other considerations include whether the post quarry landscape will fit in with its context, whether the landscape will provide opportunities for recreation and whether the site will produce sufficient income to sustain its long term management. Natural re-vegetation was considered as the tenth scenario.

In a survey, the ten scenarios were rated according to their attractiveness based on a 5-point categorical rating scale: 1 (very unattractive) to 5 (very attractive) (Lange and Legwaila, 2012). Participants were also asked to note characteristics of the landscape that attracted their attention and indicate whether they liked them or not.

2.2. Visualization and stimulus selection

Simmetry 3D visualization software was used to develop the different scenarios. The base data was obtained from the sources listed in Table 3, and edited using the software indicated before being imported. These operations were carried out on a standard laptop PC with a 600 GB hard disk space, 4GB RAM, and an ATI Mobility Radeon DH 4500 series graphics card with 512 MB memory (see Legwaila, 2012).

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Scenes captured from the visualizations were taken at predetermined viewports at 50, 300, 500, 2800 and 6400 meters from the quarry. The viewing distances were based on the USDA framework for landscape viewing distance zones being the foreground, middle ground and the background (USDA, 1995). However, more focus was concentrated on the closer zone because, as Hull & Bishop (1988) concluded, it was expected that more inflection in the perception of attractiveness would occur here. Thus, three viewpoints (50, 300 and 500 meters) were located within the foreground distance zone and one each in the middle ground and background zones. By displaying different levels of detail and complexity depending on the distance of the viewpoint, each image represented a unique perspective of the quarry. Figure 1 shows the 10 images of all treatments captured at the same distance of 300m.

2.3. Survey participants and process

To take part in the survey students at the University of Sheffield were recruited through word of mouth, email-lists and poster advertising (Dearden, 1981; Lange et al., 2008). The 70 participants came from different disciplines and countries of origin including Botswana, China, Mexico, Japan, Britain, Turkey, and Zimbabwe (Lange and Legwaila, 2012). They included 29 landscape students; 21 students from other built environment disciplines (Architecture, Town and Regional Planning, and Engineering) and 20 students from other departments. The participants did not receive a reward for taking part.

Each participant carried out the survey independently of the others so that they exerted personal control over the running of the experiment. They were free to watch each image for as long as they deemed necessary in order to assess it. The images were randomized for each participant. This was done to eliminate potential bias that could result from presenting them in some form of sequence, e.g. in a descending or ascending order based on distance (Green, 2010; Lange et al., 2008). The randomizing was done using a Microsoft PowerPoint 2007 slide randomizing macro code.

Each image was presented using a ceiling-mounted standard data projector with a resolution of 1024 x 768. The viewing distance was 2.5m in front of and perpendicular to the center of the screen so that the images occupied a large portion of the participant's field of view. This was to facilitate a sensation for the participants of being in the landscape, creating a certain level of immersion (Bishop and Lange, 2005). The surveys were carried out in a seminar room with participants seated at a 75cm high table with an eye level at approximately 120 cm above the floor, depending on the height of the participant.

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3. Results

It was estimated that the survey would take 30 minutes to complete, however, the average duration was 41 minutes, which equated with an average of 49 seconds per image. The time taken to complete the survey varied over a large range of between 11 and 77 minutes. This variation was largely due to the fact that those who completed the survey in a short time choose not to answer the open-ended question about particular landscape features that attracted their attention. However, the attractiveness ratings provided by all the participants were used in the analysis.

3.1 Analysis of landscape features and characteristics

To identify the landscape features and characteristics with a strong relationship to attractiveness of reclaimed limestone quarries, it was assumed that these characteristics would be most prevalent in the highest- and lowest- rated slides (Rabinowitz and Coughlin, 1970). This notion was based on research by Lange (2001), Steinitz (1990) and Rabinowitz and Coughlin (1970) in which it was concluded that judges tend to agree more on ratings of attractiveness of images rated at the extremes of a rating scale.

The fifty images were sorted from highest to lowest rated and the high and low extreme 5% of the images were identified and a further 5% (2 x 3 images) of the images were identified on either side of the mean rating score for all the images. A cross-tabulation was then performed between the rating scores for each of these twelve images to identify the characteristics that participants had noted against them and to establish whether or not they liked those characteristics. Each image was isolated to perform this function and the number of times a participant indicated they liked, disliked or were neutral about the different characteristics were aggregated shown in Figure 2. Only those characteristics that were identified by at least five per cent of the participants were noted for this analysis.

In the lowest rated images, more participants disliked visibility of the quarry wall in the natural recovery scenario at the furthest distance, 6400m. The other characteristics that were most disliked were (in order) lack of vegetation (plain), dark colours (shadows and dark tree canopies) and great distance. In describing the “distant” character, participants implied that the distance between the viewpoint and the quarry was such that they were not able to discern the form and character of the quarry landscape rendering identifiability and coherence (legibility) of the quarry in the landscape very low. All three of the lowest rated images were from the furthest viewpoint set for the study (6400m).

In the visualizations that were rated highest, most people indicated that they liked images with water. As indicated in Figure 3, trees, vegetated quarry wall and visible quarry wall were also highly liked at the foreground distances of 50m and 300m. Comments from the participants indicated that visibility of the quarry wall was appreciated as a symbol of the quarry history at which distance the quarry wall could be seen through the vegetation.

The results presented in Figure 4 show that the majority of average rated images were captured at a distance of 550m. Trees were the most liked characteristic in these images. Overall, participants liked the dry rock walls in the landscapes.

Three of the images in the average category were captured from the foreground distance in the Bench-planting + Agriculture scenario. These had views of a dry rock wall and plain grass. At 50m and 300m participants disliked the visibility of the quarry walls but more people liked their visibility at 550m. This was the same for the Natural recovery scenario at distance 550m. Vegetation and the effects of distance decay limited visibility of the quarry wall. More people liked the trees and variety of vegetation in the image.

Table 4 shows the correlation coefficients for the relationships between each of the elements and the participants' ratings. The positive coefficients for water, trees and rock indicate that as each of these landscape features increased from low to high, the corresponding rating also increased. Overall, trees had the highest statistically significant correlation with attractiveness ratings for the scenes ($R = 0.841$, $p = 0.000$) and rock had the lowest with a statistically insignificant correlation coefficient ($R = 0.121$, $p = 0.401$). The amount of plain grass visible in the scene, on the other hand, had a negative relationship with the ratings of the landscapes ($R = -0.775$, $p < 0.0005$). That is, as the amount of plain grass increased, the score for the landscape decreased.

3.2 Assessments of the Scenarios

Table 5 shows the five characteristics that were most liked and most disliked in each scenario. In all scenarios, participants liked trees and disliked dark colours. In scenarios Backfilling + Agriculture, Bench-planting + Agriculture, and Restoration blasting + Agriculture, which represented agricultural after-use, they also liked the vegetated quarry wall and the dry rock wall. They disliked visualizations with distant views characterized by flat topography and a lack of vegetation variety. They also disliked the visibility of the quarry wall in scenario Bench-planting + Agriculture.

https://doi.org/10.1080/17480930.2018.1561387

In scenarios Backfilling + Nature conservation, Bench-planting + Nature conservation and Restoration blasting + Nature conservation, which represented nature conservation after-use, they liked water the most. They also liked reflection of elements in the water as well as the vegetated quarry wall.

Visibility of the quarry wall was liked in scenario Restoration blasting + Nature conservation while it was most disliked in scenario Bench-planting + Nature conservation. Just like scenario Bench-planting + Agriculture discussed above, Bench-planting + Nature conservation represented the bench planting treatment of the quarry wall. Other disliked characteristics were lack of vegetation and scenes that looked unnatural.

For scenario Backfilling + Woodland, Bench-planting + Nature conservation and restoration blasting + Woodland, which represented woodland after-use, participants liked the variety of trees in the landscape, whereas lack of vegetation, random patterns in the landscape and scenes that looked unnatural were all disliked.

Scenario Natural recovery, which was the lowest rated scenario, presented a variety of vegetation and created a sense of mystery, which participants liked. They disliked the visible quarry wall in this scenario, which had minimal amount of vegetation, exposing much of the quarry wall. The highly visible quarry wall created an unnatural feel to the landscape, which participants did not like. However, participants liked some scenes captured in this scenario, which they thought looked natural.

For all scenarios, 65 participants mentioned the characteristic “looks natural” and out of this number, fifty-nine (90%) indicated they liked scenes with this characteristic while three (5%) disliked it and three (5%) were neutral. On the other hand, twenty-seven participants mentioned the characteristic “Looks unnatural”. Seventeen (63%) of these participants disliked the characteristic, while two (7%) liked it and eight (30%) were neutral about it. Overall, it showed that people liked scenes that they perceived as looking natural more than those that looked artificial.

In summary, Tables 6 and 7 show that participants best-liked scenes containing woodland following Restoration Blasting as a quarry wall treatment, whereas the abandoned quarry was liked the least. This implies that as the level of perceived human influence increased from woodland to abandoned quarry, participants’ ratings decreased. Mean ratings based on the quarry wall treatment also suggest that participants liked a certain level of visible quarry wall.

https://doi.org/10.1080/17480930.2018.1561387

That is, they neither liked the quarry wall totally covered as in the backfilling treatment, nor did they like scenes with extensive areas of exposed rock, as in the bench-planting treatment and the abandoned quarry.

A paired sample t-test was conducted to establish whether there was a significant difference in how scenes were rated based on the different land-uses and quarry wall treatments. The results in Table 8 show that there was an insignificant difference between Agriculture and Nature conservation as well as Nature conservation and Woodland land-uses. Table 9 shows that there was also no significant difference between Restoration blasting and Backfilling treatments.

4 Discussion

The responses to the question regarding landscape characteristics were reliant on the participants' ability to detect, recognize and describe the different elements that influenced their ratings for attractiveness of the reclaimed limestone quarry landscapes. However, landscape description is likely to be a difficult task for people who do not have a background in landscape or related disciplines, especially. This is attested by the fact that 20% of the participants did not answer the question on landscape description. Coupled with this, limitations in vocabulary concerning landscape features may have also contributed to some of the vague descriptions or non-description of the landscapes. This was compounded by the fact that 20% of the participants were from non-native English speaking countries. Comments such as "water feels very cold" and "it smells like water" can attest to the difficulty with which participants may have had in expressing their perception and describing the landscapes.

To circumvent this problem, a checklist in which participants could indicate the characteristics and/or features, which they thought applied to each of the scenes, could have been used (Craik, 1968). This could possibly have provided a more level platform in terms of descriptive vocabulary for identifying the landscape characteristics. On the other hand, the vocabulary provided could be unfamiliar to some participants, hence difficult to apply.

Previous studies such as those by Kaplan and Kaplan (1972), Rabinowitz and Coughlin (1970) and Zube et al. (1974) concluded that scenes that contained naturalistic features and/or characteristics are preferred to those with anthropogenic influences. Kaplan et al. (1972) described natural scenes as those with "grassy stretches, meadow scenes, dense foliage and stretches with more or less woodland". Zube et al. (1974) on the other hand, listed topography, water, trees, and shrubs under natural features. In the current study, the site was assumed to have been in a natural setting, however quarrying and some of the reclamation schemes used, represented varying levels of anthropogenic influence. On this basis, the naturalistic scenes in this study were those containing water and non-agricultural vegetation that would require some management. The quarry wall, dry rock wall and the farmhouse were taken to show human influence. The results showed that participants preferred natural looking landscapes to those having extensive signs of human influence (Kaplan and Wendt, 1972; Steinitz, 1990). Scenes with vegetation were liked, where the majority in this study was trees, suggesting that trees played a major role in the perceived attractiveness of landscapes (Dobbie and Green, 2012). Vegetated rock faces enhanced the attractiveness of the quarry landscape. A high degree of variation in vegetation in terms of colour and texture was also an important factor influencing perceived attractiveness.

According to Motloch (2000), visual characteristics of water are influenced by the environmental characteristics of the setting within which the water exists. In this study, the most mentioned or implied characteristic of water was reflection, especially of vegetation, quarry wall and the sun that gave the water a different character in the various scenarios and distances. Rabinowitz and Coughlin (1970) found that the colour of water had an influence on how scenes were perceived where scenes with clear water were highly rated while those with cloudy water were rated low. In this research, the reflection of thick vegetation resulted in the darkening of the water colour. People liked clear water or at the best, ‘blue water’, which resulted from reflection of a blue sky. Dark water was regarded “dirty” by some participants and rated low. Notwithstanding this perception, scenes with water were rated high or average compared to others even when people disliked the dark colour of the water. This confirms that people generally liked scenes with water that they perceived to be clean, where clarity was the main aspect in determining perceived cleanliness. The presence of reflections of other landscape features was also regarded positively, (see Craik, 1975; Steinitz, 1990 and Zube et al., 1974).

In nature, darkness of water colour may be caused by factors other than reflection. Contamination can be a major challenge, however as Shrivastava et al. (2008) and Saito et al. (2002) have noted, natural systems are able to purify water. For quarry sites, such natural processes may be curbed by the sterility of the sites and the usual unavailability of water inlets and outlets in sites that may result in stagnation of the water. Adverse chemistry of the water may inhibit natural degradation of contaminants. To maintain viable biological activity

https://doi.org/10.1080/17480930.2018.1561387

ecological measures may be applied, including planting of reeds or other aquatic plants that have the ability to clarify water by oxygenating it and, absorbing nutrients that encourage algal development, as described by Shrivastava et al. (2008). The technical feasibility of incorporating water into schemes may need to be considered, especially in limestone terrains where surface water tends to be absent.

The majority of participants indicated their dislike of a highly visible quarry wall, tending to prefer quarry walls which were either totally covered with soil and vegetated or where they were slightly obscured by patches of vegetation. The results showed high attractiveness values for Backfilling and Blasting treatments, as compared with Bench-planting and Abandoned quarry, where the latter pair had relatively high rock exposure. However, it was also evident that participants liked to see a certain amount of rock. Comparing the ratings based on the type of quarry wall treatment revealed that overall, Restoration blasting, which had visible rock, was preferred over Backfilling in which the rock was totally covered with soil and vegetation. This confirms that participants like reclaimed limestone quarry landscapes that exhibit some industrial and geological archaeology. This is in agreement with Lange et al. (2008); Steinitz (1990), Helliwell (1978), Rabinowitz and Coughlin, (1970), Cripps et al. (2007). Baczynska et al. (2018), Department of Environment (1989). Thomas (2004) and Williams (2011) provide a number of examples of the industrial archaeological resource potential of reclaimed former quarries that can also provide valuable wildlife habitats and opportunities for education and recreation. Cerver (1995), in particular, draws attention to the invaluable habitats for some animal and plant species that former quarry rock faces provide. Even though Restoration blasting was found to produce attractive landscapes, overall, as the detail of rock on these landscapes becomes more pronounced at closer distances (50 and 300m), Backfilled quarry walls were found to be better, indicating that participants did not like highly exposed views the quarry rock face when viewed from close distances.

Certain patterns emerged in the ratings for different land-uses. For the Agriculture after-use, ratings were highest for the Backfilling treatment and low for Bench-planting. In this land use, there was a dry stonewall and a farmhouse that are typical features of the landscape of the UK Peak District National Park and would probably be familiar to students based at Sheffield University. However, exposed rock is an element for which participants indicated a lower score. A combination of this and an exposed quarry wall probably caused participants to dislike the scene. However, the scenario Restoration blasting + Agriculture, which had patches of grass in the quarry wall, had a very small mean difference with Backfilling + Agriculture. In this case, these two were most preferred to Bench-planting and Natural recovery, which had more rock that is visible.

Ratings for the Nature conservation land-use were highest for Blasting and lowest for Bench-planting and Blasting were preferred over Backfilling. This could be due to a combination of factors; firstly, the visibility of a medium amount of rock was preferred to either none or a large expanse. Secondly, and most importantly, the reflection of the rock surface in water had a more profound influence on the participant's perception than the reflection of solid vegetation, which tended to cause the water to look dark, which as mentioned above, was disliked by participants.

In the Woodland scenarios, ratings were highest for Blasting and equal for Backfilling and Bench-planting treatments. However, because of the high density of trees, the quarry wall was totally obscured. Thus, it was impossible to discern the type of wall treatment that was applied in each of the woodland scenarios. This is evident in the results in that the mean differences between the three scenarios with this land-use (Backfilling + Woodland, Bench-planting + Woodland, and Restoration blasting + Woodland) were very small.

5. Conclusions

The type of treatment, envisaged after-use of the quarry and the distance from which it will be visible are important factors to consider when designing a quarry site for closure. They all have an effect on the perception of viewers, which can translate to the level of acceptance and the resultant usage of reclaimed quarry sites.

It is a common feature of limestone and other hard rock quarries that the amount of material available for back-filling or covering faces can be very limited (Cripps et al., 2007). The different techniques applied in this study require different types and quantities of materials to be available. Knowledge gained from this study can be used to develop quarry reclamation schemes that involve judicious use of scarce materials and resources. Selective treatment of the quarry landform can prove to be advantageous in this regard. The different portions of the quarry could be treated differently with techniques selected according to viewing distances and environmental conditions. Schemes involving minimal amounts of exposed rock, trees and water, with minimal use of soil materials, may be more appropriate, in particular if they can satisfy aesthetic requirements.

https://doi.org/10.1080/17480930.2018.1561387

Digital landscape visualizations and landscape visual assessment tools applied in this study as well as the results thereof, can be used as a tool for supporting selection of reclamation schemes for different after-uses. They can be helpful in establishing an understanding about landscape in order to guide public discussion and decision making regarding the direction of reclamation; hence minimizing chances of conflict among different interest groups, (Bishop & Lange, 2005; Loh et al., 1992), which in turn has a huge impact on the success and sustainability of post quarrying landscapes.

Even though the study focused on the reclamation of limestone quarries in England, the findings are applicable to other countries and rock-types, depending upon the environment and regulations in those places.

Acknowledgement

I wish to acknowledge that this research would not have been possible had it not been through the financial support of my employer, The Botswana University of Agriculture and Natural Resources. I would also like to thank the University of Sheffield's Department of Landscape for the occasional financial support extended to me to attend workshops and conferences.

Thanks to Dr. Ed Morgan for providing the landscape visualization software and technical support whenever it was necessary.

I am also grateful to Dr Frank Spode for finding time in his busy schedule to take me around the Derbyshire Peak District to see the many different limestone quarries in the area. This was very helpful especially that it happened in the early stages of my research. The value of knowledge I gained from these trips cannot be overstated.

Thanks to the former and the current quarry managers at Lafarge Cement, Hope Works, Mr. John McGough and Mr. Jeremy Elvins respectively and the management at Hope Cement works for providing access to the quarry for part of my research. I am also thankful to the quarry manager at Tunstead Quarry Tarmac Ltd, Mr. Philip Fletcher and its management for also providing access to the quarry.

I thank Mr Elliott George the reclamation manager at Tarmac Ltd. for showing around their reclaimed quarry sites. This gave me an insight on the processes and the end products of different reclamation schemes for different types of quarries. It was invaluable information that informed part of my research.

https://doi.org/10.1080/17480930.2018.1561387

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Published in: International Journal of Mining Reclamation and Environment
https://doi.org/10.1080/17480930.2018.1561387

Tables

Method	Characteristics
Backfilling 	Part or complete filling of a quarry void with soil, soil forming materials, and/or waste rock in order to restore the original grade or to create a new landform. May include recreation of wildlife habitats and planting or reuse for agriculture. Provides the opportunity to dispose of processing or other waste materials, depending upon their properties and local planning and waste disposal regulations.
Bench planting  	Placement of soils on quarry benches and planting with trees to obscure quarry landform. This may be combined with landscaping of quarry floor and surrounding area. Landscaping may include water bodies. Soils are stripped from the rock outcrop prior to quarrying may be used. The presence of plant roots and seeds will promote the growth of vegetation natural to the area. Management of the soils and vegetation, particularly with respect to irrigation, and erosion control may be necessary. Many limestone formations are covered with thin veneers of soil, such that it may be necessary to import or manufacture soils, which are then planted. The growth of vegetation sufficiently tall and dense to concealing rock faces can take many years or may not be feasible, depending on the soil and environmental conditions
Restoration blasting 	The final phase of blasting is used to create an appropriate landform, including rock faces, scree slopes and bock buttresses. This may include landscaping, placement of soils or soil forming material for habitat creation and re-vegetation. The forms could be created by partial backfilling of the lower parts of faces with waste rock or other materials. Provides the opportunity to incorporate simulated natural landscape features into schemes, however the rock mass is liable to be heavily fractured, with the possibility that rock faces may become unstable and thus become hazardous such that they require scaling or other stabilization measures. The creation of the landforms requires carefully planned blasts,

https://doi.org/10.1080/17480930.2018.1561387

	which are challenging to design.
Roll-over slopes  	The sharp top lip of the quarry is removed either by rounding the edge or by placing fill on benches to give a curved profile at the top of the quarry excavation. This may be done by pushing material over the top edge of the quarry and spreading it on the underlying benches to create gentle slopes over quarry faces. Alternatively, it may be achieved by selective blasting of the tops of the upper faces in quarries. The method is particularly successful where removing the top edge of the quarry excavation overcomes the unnatural appearance of the quarry. This can be the case where it is not possible to view the quarry from an elevated position, the excavation is flooded or vegetation or other remedy mean that the lower parts of the quarry do not have high negative impact.

Table 1: A description of commonly used quarry reclamation methods

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Scenario	**Treatment**	**Post-quarrying land-use**
1	Backfilling	Agriculture
2	Bench-planting	Agriculture
3	Restoration blasting	Agriculture
4	Backfilling	Nature conservation
5	Bench-planting	Nature conservation
6	Restoration blasting	Nature conservation
7	Backfilling	Woodland
8	Bench-planting	Woodland
9	Restoration blasting	Woodland
10	Natural recovery	Natural

Table 2: The different combinations of quarry treatment and post-quarrying land uses gave ten different quarry reclamation scenarios.

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Data Type	Data Source	Raw Data Format	Editing Software	Visualization data Format	Data Resolution
Height (Model Terrain)	Hope Quarry, Derbyshire, UK	DWG	AutoCAD, ArcGIS	ASCII	Contour interval = 5m Scale 1:50000
Height (Context Terrain)	EDINA (Ordnance Survey map data)	DTM	ArcGIS	DTM	Contour Interval =10m Scale 1:50000
Detailed Terrain Textures	GeoStore	JPEG	Photoshop, ArcGIS	JPEG	25cm
Context Terrain Textures	Geo Store, Google Earth	JPEG	Photoshop, ArcGIS	JPEG	25cm
Images for surface textures	Site photos (Hope Quarry)	JPEG	Photoshop	JPEG	Variable

Table 3: Raw data sources and data formats used in the study

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Element	**Correlation coefficient (R)**	**Significance**
Water	0.403	0.004
Trees	0.841	0.000
Rock	0.121	0.401
Grass	-0.775	0.000

Table 4: Relationship between the proportions of different elements and mean rating scores of all scenes combined

Scenario	**Liked**	**Disliked**
Backfilling + Agriculture	1. Trees 2. Vegetated quarry wall 3. Dry rock wall 4. Looks natural 5. Rolling topography	1. Dark colours 2. High tree density 3. Form, Lack of vegetation variety, Colour contrast 4. Balance
Bench-planting + Agriculture	1. Vegetated quarry wall 2. Tree, Dry rock wall 3. Looks natural 4. Unity 5. Building	1. No vegetation (Plain) 2. Visible quarry wall 3. Low tree density, Flat topography 4. Looks unnatural, Distant 5. Balance
Restoration blasting + Agriculture	1. Vegetated quarry wall 2. Trees 3. Building 4. Dry rock wall 5. Unity	1. Low tree density 2. Dark colours 3. Distant 4. Flat topography, lack of variety, Random pattern
Backfilling + Nature conservation	1. Water 2. Trees 3. Composition, Hidden quarry wall 4. Reflection 5. Rolling topography	1. Dark colours 2. High tree density 3. No vegetation (plain) 4. Flat topography, Leaf texture, looks unnatural
Bench-planting + Nature conservation	1. Water 2. Vegetated quarry wall 3. Trees 4. Unity 5. Balance	1. Visible quarry wall 2. No vegetation 3. Looks unnatural 4. Dark colours 5. Form, High tree density
Restoration blasting + Nature conservation	1. Water 2. Vegetated quarry wall 3. Trees 4. Visible quarry wall 5. Looks natural	1. Dark colours 2. Low tree density, No vegetation, Looks unnatural 3. Dry rock wall
Backfilling + Woodland	1. Trees 2. Variety of trees 3. Vegetated quarry wall 4. Flat topography, Green colours 5. Colour contrast	1. Dark colours 2. Distant 3. High tree density 4. Hidden quarry wall, Random Pattern, Visible quarry wall, Dry rock wall
Bench-planting + Woodland	1. Trees 2. Variety of trees 3. Visible quarry wall 4. Looks natural 5. Hidden quarry wall	1. Dark colours 2. Form, no vegetation 3. Looks unnatural
Restoration blasting + Woodland	1. Trees 2. Variety of vegetation 3. Vegetated quarry wall 4. Reflection, Rolling topography 5. Unity, Mystery	1. No vegetation, Dark colours 2. Distant 3. Form, Random pattern
Natural recovery	1. Trees 2. Variety of vegetation 3. Looks natural 4. Mystery, High tree density	1. Visible quarry wall 2. Colour contrast 3. Random pattern 4. Looks unnatural

Table 5: A summary of the top five most liked and disliked characteristics in each scenario

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After-use	Mean score	Standard Deviation
Woodland	3.35	0.959
Nature conservation	3.29	1.010
Agriculture	3.25	0.965
Natural recovery	2.90	1.126

Table 6: Mean scores for all participants based on the type of after-use used in the different scenarios

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Quarry wall treatment	Mean score	Standard Deviation
Restoration blasting	3.37	0.953
Backfilling	3.30	0.986
Bench-planting	3.21	0.992
Natural recovery	2.90	1.126

Table 7: Mean score for all participants based on the type of quarry wall treatment used in the different scenarios.

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	t	**Significance**
Agriculture - Nature conservation	1.238	0.216
Agriculture - Woodland	2.829	0.005
Agriculture – Natural recovery	6.225	0.000
Nature conservation - Woodland	1.692	0.091
Nature conservation – Natural recovery	4.168	0.000
Woodland – Natural recovery	6.427	0.000

Table 8: Comparison between ratings of the different scenarios based on the type of after-use applied in the quarry landscape.

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	t	**Significance**
Backfilling – Bench-planting	2.703	0.007
Backfilling – Restoration blasting	1.903	0.057
Backfilling – Natural recovery	6.225	0.000
Bench-planting – Blasting	5.043	0.000
Bench-planting - Natural recovery	3.398	0.001
Blasting - Natural recovery	5.835	0.000

Table 9: Comparison between ratings for the different scenarios based on the type of quarry wall treatment applied in the quarry landscape.

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https://doi.org/10.1080/17480930.2018.1561387

Figures

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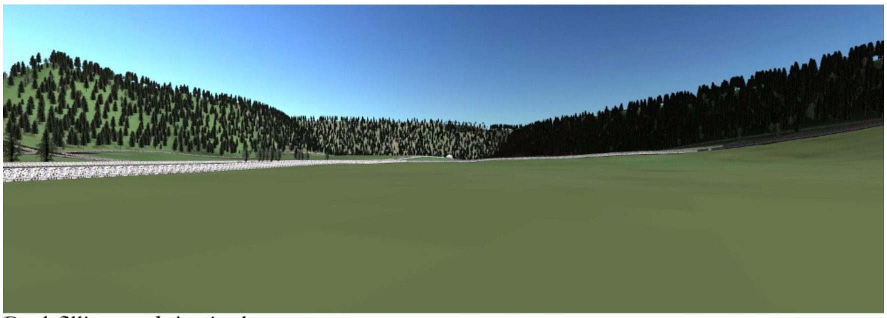
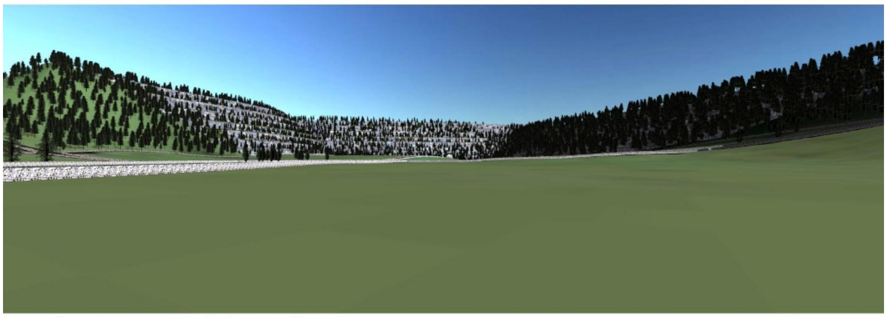
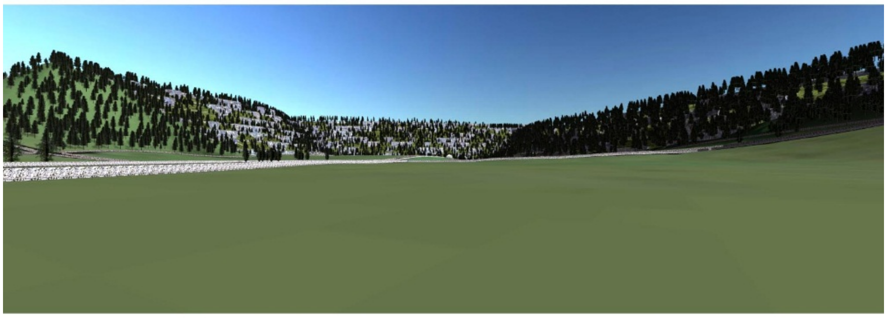
https://doi.org/10.1080/17480930.2018.1561387


Backfilling and Agriculture


Bench-planting and Agriculture


Restoration blasting and Agriculture


Backfilling and Nature conservation


Bench-planting and Nature conservation

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Restoration blasting and Nature conservation

Backfilling and Woodland

Bench-Planting and Woodland

Restoration blasting and Woodland

Natural recovery

Figure 1: A sample of scenes of all the ten quarry treatments views at a distance of 300m.

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https://doi.org/10.1080/17480930.2018.1561387

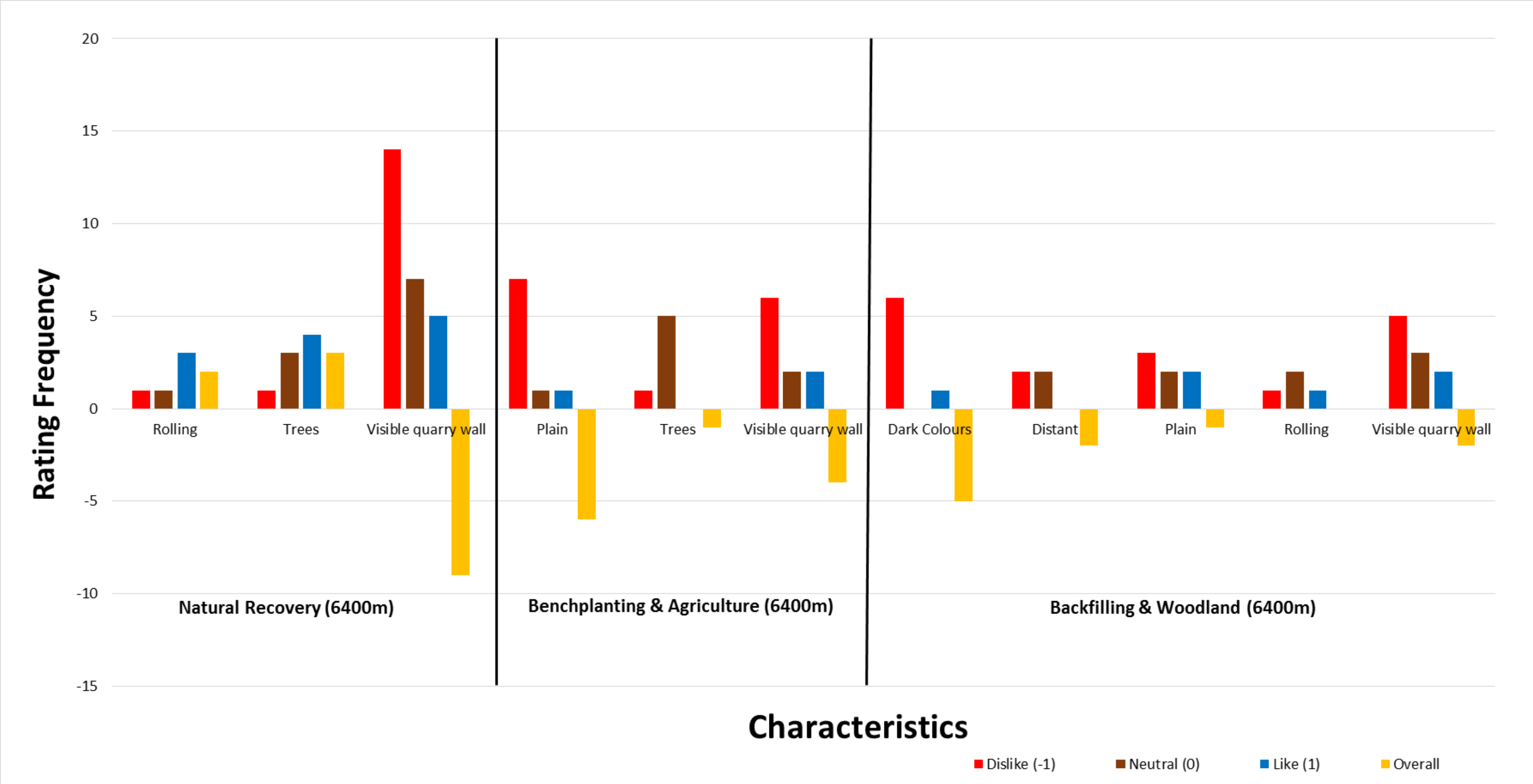

Figure 2: Landscape characteristics identified in the low-rated images. This figure shows the frequency at which each image was rated.

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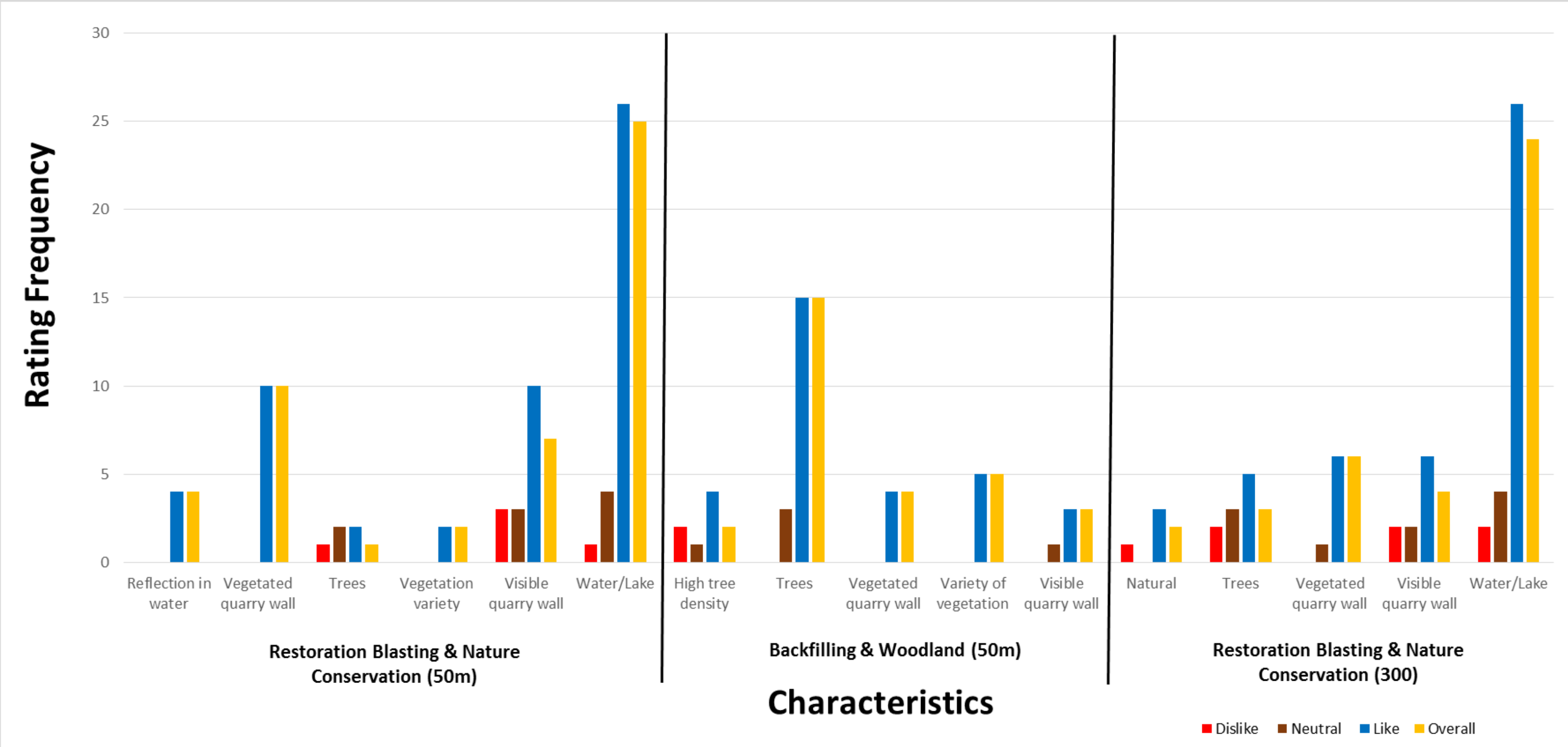

Figure 3: Landscape characteristics identified in the high rated images. This figure shows the frequency at which each image was rated.

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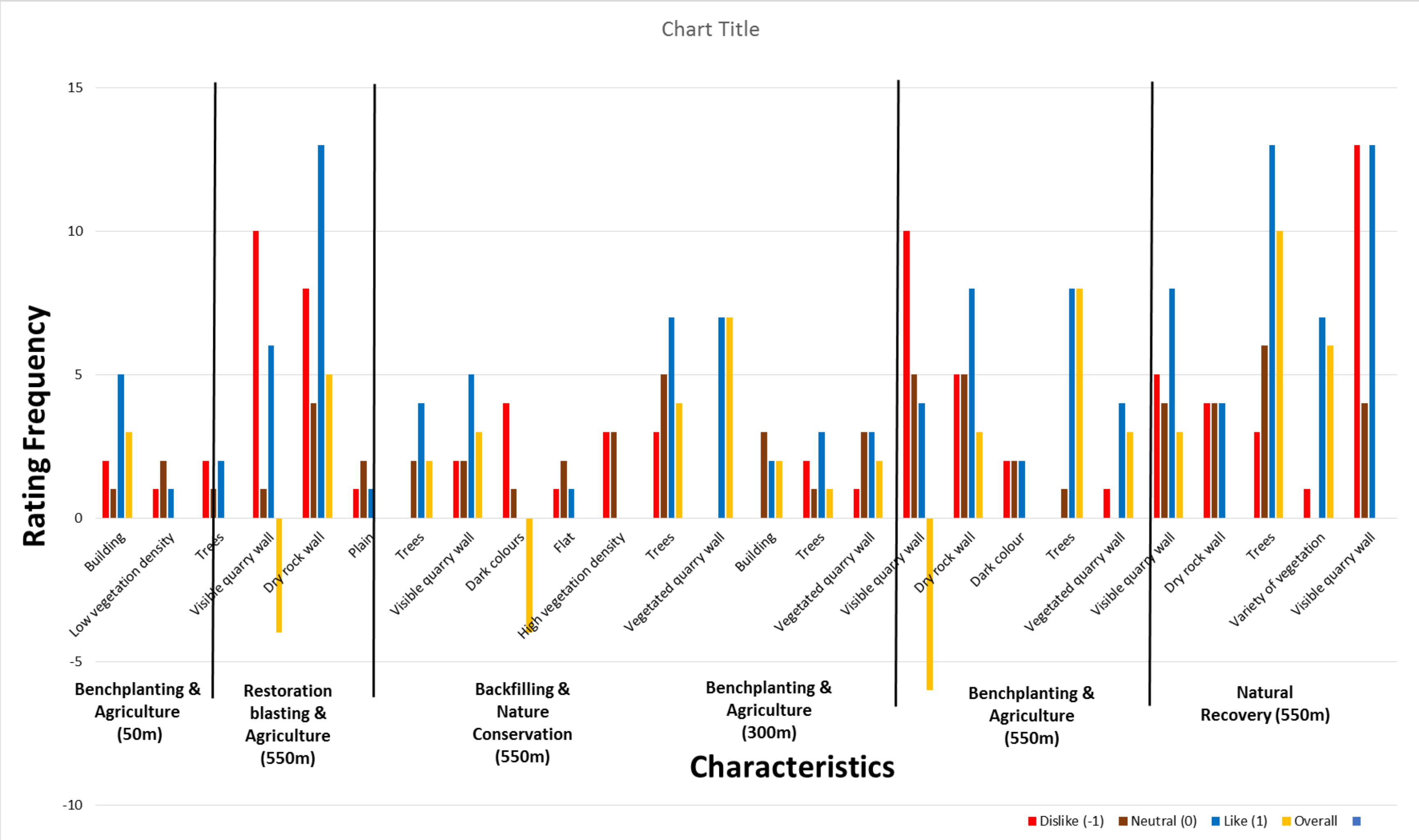

Figure 4: Landscape characteristics identified in the average rated images. This figure shows the frequency at which each image was rated

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