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The proposal to transform an old limestone quarry into a botanical garden with a rainforest zone: a case study

Key words: biodiversity, biodiversity conservation, reclamation, sustainability planning, green infrastructure, ecological restoration

Introduction

Landscape can be defined in many different ways. The definition of landscape as a synthesis of natural and cultural environments seems most appropriate (Klink et al., 2002). The analysis of individual components of landscape as well as the degree, in which they influenced the environment, results in identifying the following landscape types: primeval, natural, cultural and devastated. The last type refers to the areas with high degree of urban and industrial development (Bastian & Bernhardt, 1993).

The fact that more and more degraded areas form modern urban spaces is quite disturbing. The fast pace of degradation of the Earth's surface stimulates looking for appropriate methods of its prevention and liquidation (Bogaert, 2006; Naveh, 2007). The changes in spatial structures and soil quality as well as the existing threats should stimulate strong efforts to optimise land use. Apart from prevention of environment degradation, efforts should be directed at recreating the already devastated environment (Aronson, Handel & Clemants, 2007; Arifin & Nakagoshi, 2011). Land reclamation has the restoring function, as it recreates the ecological and utilitarian values of the environment. Reclamation of the degraded areas can be defined as all activities aiming at restoring biological and usable functions, to soil in particular. Reclamation includes the lands degraded in consequence of human living and economic activities. Moreover, the aim of reclamation should be rejuvenation of the destroyed landscape in harmony with the surrounding area, simultaneously promoting biodiversity (Gaidin, 2011; Do, Kim, Kim & Joo 2014; Łuczak, Kusza, Słonina & Borecka, 2019).

Closed limestone quarries are the locations, which definitely require such

intervention. In many industrialised countries, excavation of calcium carbonate (limestone) resulted in considerable modifications of landscape and the whole environment (Gunn & Bailey, 1993). The appropriate definition of the future function of the degraded area, such as a closed limestone quarry, is of key importance. In view of common urbanisation and its influence on natural environment, the degraded areas serve mainly to preserve biodiversity (Khew, Yokohari & Tanaka, 2014).

However, it is worth considering the possibility of combining this function with creation of extra tourist and leisure areas. Such areas are considerably different from everyday environment and offer natural and cultural benefits as well as adequate facilities. The opportunity for development of new leisure areas in cities lies in the zones, where natural qualities have been lost or are scarce. Reclamation provides such opportunities and, by adapting a degraded area, creates its new image by shaping new, multifunctional spaces (Paulo, 2005).

The Botanical Garden in Shanghai is an example of the project, which could be a model for other quarries. One can find there interestingly developed space, the Quarry Garden, in particular. The quarry was transformed into an extremely attractive garden, which is not only a fascinating area to sightsee. The garden is a kind of a witness, because it tells the story of the quarry and shows the destructive anthropogenic activity. One could say that the developed quarry was returned to nature. The Quarry Garden has an important role – education of visitors' awareness, desquarrye the lack of the landscape reconstruction activities.

Therefore, landscape shaping should be understood as all activities aimed at its reconstruction. The objective of these activities is to fit the area into natural environment. These activities refer mainly to the environments changed in consequence of human activity. Establishing a botanical garden can be one of the ways of returning the degraded landscape to nature. Within a specific form of nature protection, each botanical garden has the following functions and duties: protection of biodiversity, in particular regarding the endangered species, participation in scientific research mainly aiming at protection of endangered species, plants protection education as well as cultivation of the endangered species of plants (*ex situ* protection), in order to introduce them into natural environment (Kirichenko & Kenis, 2016). It is also worth emphasizing that botanical gardens do not focus on scientific and research activities only. They form an important element of urban greenery systems. They are also a valuable leisure zones for inhabitants of many towns (Grzonkowska, 2014).

Botanical gardens may also offer education opportunities for the society in different aspects. Beautiful floral compositions can be the source of inspiration to anyone, who wants to know more about the world of plants. In this way, every botanical garden can stimulate increased contact with nature and better understanding of the world of plants (Holttum, 1999; Norton, Evans & Warren, 2016).

The aim of the article is to present the proposal of developing the closed limestone quarry and creating a botanical garden. The presented project takes into consideration all the necessary func-

tional and spatial elements, with maximum preservation of the existing environment. An additional objective is to create an interesting location, attractive to many social groups, which maintains natural heritage of the Opole region in education and natural sciences, including botanical science.

Study area

The project area is located in Gogolin, a town in Opole Province (southwest Poland) (Fig. 1). The garden is located in geographical coordinates: latitude – 50°29′15″ N, longitude 18°02′38″ E. The town of Gogolin has considerably influenced the Opole region culture. The town is recognized all over the country thanks to a folk song about "Karlik and Karolinka from Gogolin". The town has also a very interesting history. Initially, the town's area was strictly agricultural. Throughout the years, the town turned into an industrial centre due to limestone exploitation centres. One can still see the historical, 19th century limestone furnaces in the area.

The area of the planned botanical garden is situated on the border of the Silesian Upland and Lowland. The area of the botanical garden is post-industrial. Features of the landscape are varied. One can notice such formations as slopes, hills, gorges and vertical rock precipices. The existing conditions favour large biodiversity of habitats. Rendzina brown soils can be found in the planned area of the botanical garden. They are present in arable lands. The outer soil layer was removed or moved due to exploitation in the old quarry. That is why mostly shallow soils with a high pH can be found in the area. As far as the climate is concerned, the area has mild winters with average temperatures not exceeding –2°C. In summer, the highest temperatures occur in July (above 25°C). The growing season is 225 days in the area. Average precipitation is about 600 mm per year. These conditions favour plant vegetation. Diverse microclimatic conditions (extremely dry and moderately humid) are present within the limestone quarry. There is a marshy habitat in the area designed for the garden – rainforest.

The area proposed for the Opole Botanical Garden is a former quarry, with

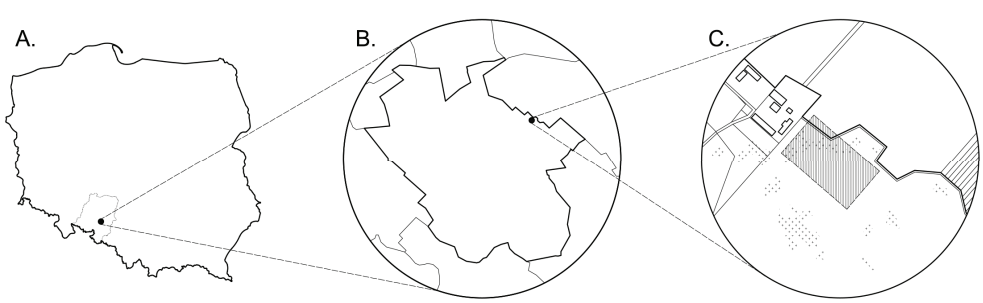

FIGURE 1. A – location of Opole province and Gogolin in Poland, B – the proposed area of the Opole Botanical Garden in Gogolin, C – location of the rainforest garden in the Opole Botanical Garden in Gogolin (own work)

biodiverse habitats. Different stages of natural succession can be observed there. The quarry area in its main part is characterised by the presence of synanthropic plants and an early succession stage. Due to the fact that the quarry has not been used for over 50 years, most area is overgrown with semi natural plants, mainly the green and grassy vegetations. The described area is surrounded by farming areas and woodland. Woodlands planted during land reclamation are present in the south and west side. Mixed forests and small wet-ground sub-continental forest areas can be found in the neighbourhood, with such tree species as *Fagus sylvatica* L., *Quercus robur* L. and *Carpinus betulus* L. These are the remains of the primeval riparian forests growing in the area. A strip of trees growing on the western side of the area is also an important element. It has insulating and protective functions, in particular from the strong, west wind. The most important plant communities observed in the quarry are rock, ruderal, clear-cut, grassland, meadow and pasture, fringe, wood and overgrowth.

Methods

The research on the possibility of developing closed limestone quarries covered a few aspects. In the first stage, dendrological inventory was taken, which was the basis for proving the need to change dendroflora structure as well as to regulate and cultivate the existing trees. The most numerous tree species are *Crataegus monogyna* Jacq., *Malus* sp., *Prunus spinosa* L., *Robinia pseudoacacia* L., *Sambucus nigra* L. Next, the required spatial, natural and communication analyses were carried out. Each of them was performed in order to get to know precisely the surroundings and the very project areas.

The area included in the project is surrounded by zone with various functions. These functions are rather not connected and they serve different utilitarian purposes. Farm fields are the closest to the area. Mixed forests are located on the north, south and east sides. Their presence is a positive aspect. They can considerably stimulate natural succession. The area designed for allotments is located in the south-western side. This is an important element, as far as leisure activities of the inhabitants of Gogolin are concerned. This also confirms their need to commune with nature. Currently, the project area is the place of visits of occasional walkers and youth. The project area is located in a limestone quarry, opened before Second World War. Due to excavation operations, its landscape does not present any historical composition. However, limestone furnaces, which are important historical elements, require special attention. The project area has a few landscape spaces and interiors, which should be taken into consideration during the design stage. The existing sylva allows for creating a specific landscape unit, in harmony with the surroundings.

The phenomenon of natural succession dominates in the project area. The area is also an interesting example of biodiversity. The growing plants adapted to various habitats. The existing flora should be enriched in an appropriate way, so that the area does not lose its unique value. In order to achieve this, the

existing flora should be maintained as much as possible and only minor corrections should be introduced. Additionally, new plants should be introduced, from the species related to already growing in the area. The garden – rainforest area is characterised by a specific microclimate. Rich and lush vegetation with humid soil define a specific climate of any area. It is also the area with plants, which have different habitat needs. The existing plants should be adapted as much as possible in a given area. However, in order to make the area more attractive for tourism, new plant species should be introduced, interesting due to their shape, texture or colours. Thanks to the favourable habitat and climate conditions, it is possible to create a rainforest substitute in the area. In the garden – rainforest project area there is a pathway naturally created by walkers. This element confirms the need to create a similar communication system. Adding new paths should be considered, in order to make different areas more attractive.

Results and discussion

The project proposal

The main idea of the project – creation of the Opole Botanical Garden in Gogolin – is to maintain the particular biodiversity, combined with regional culture and its continuous development. This type of assumption aims not only at protection of endangered species. It also has a great role in shaping the awareness of natural environment of various social groups. It is also a place of commune with nature.

The main assumption of the themed garden – rainforest is to create a substitute of rainforest in the Opole Botanical Garden. This is possible through certain project actions, among others through selection of the existing afforestation, considering its adaptation as well as through liquidation and introduction of new trees, shrubs, perennial and climbing plants, which shall emphasise the tropical landscape type by their shapes, texture and colours. Additionally, vegetation floors should be shaped correctly, following the system present in rainforests. It is also necessary to set communication paths with appropriate surfaces and introduce additional attractions for the visitors. The above mentioned project activities are possible thanks to the particular features of the landscape. The project area is located in a lower area and it is characterised by high humidity. This is an ideal habitat for the creation of a garden – rainforest. The above assumption will undoubtedly be a major attraction of the botanical garden, not only due to diverse flora (Fig. 2).

As far as plants are concerned, the garden – rainforest project includes adaptation of the existing afforestation as much as possible. However, it is unavoidable to remove some plants from the planned pathways and other small architecture forms. Additionally, the projects includes introduction of new plant species, appropriate for the habitat as well as the species which fit the tropical rainforest image. Introduction of the protected plant species is also a necessary element, together with their appropriate location and exposition. Implementation of the above actions will result in increasing the project potential. It will also contrib-

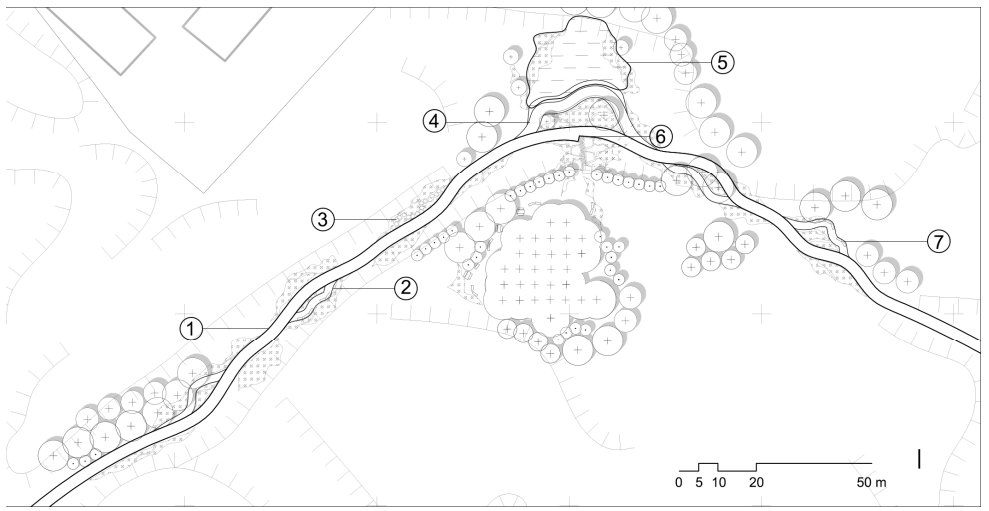

FIGURE 2. The rainforest garden plan: 1 – main wooden path, 2 – sitting place, 3 – stone steps, 4 – view point, 5 – water reservioir with waterfall, 6 – stairs, 7 – wooden benches and tables (own work)

ute to create the desired character of the themed garden – rainforest. The proposed plantings are shown in the table, together with the percentage composition of the planned trees and shrubs.

The water reservoir was designed in the current depression of the terrain. This area ideally fits the planned purpose. High slopes and the hollow terrain create an ideal location for a waterfall. The presence of water in the project area shall add aesthetic qualities. It can also be an additional attraction. The following water plants will be introduced in the reservoir: *Nymphaea candida* L., *Nymphaea alba* L. Additionally, the banks of the reservoir shall be properly shaped and enriched with water plants. An open work structure terrace, with the surface made of steel grid, was designed near the reservoir. The used materials shall increase contact with nature. Thanks to the terrace open structure, visitors will see water under their feet. Additional water sprinklers shall strengthen the illusion of close commune of people with nature.

Several types of surfaces can be differentiated in the project area. It is proposed to create the main communication route from one material. Apart from the main walkway, several side footpaths were designed; their form, materials and directions shall offer another attraction. The main walkway was designed along the currently visible beaten tracks. However, a number of deviations were planned, in order to make the route more winding. The new footpath design enables to visit individual parts of the botanical garden in a more quiet pace. The slow pace shall create the atmosphere of loss and mystery. It will also more precisely render the rainforest character. Timber is the proposed material for construction of the main footpath. It ideally fits the existing landscape, as a natural raw material. Additionally, elevation of the footpath above the terrain shall

TABLE. The proposed plantings in the project area (own studies)

Vegetable form	Plant species (percentage)
Deciduous trees	*Ailanthus altissima* Mill. (24%), *Gleditsia triacanthos* L. (10%), *Sophora japonica* L. (10%), *Catalpa bignonioides* Walter (7%), *Catalpa speciosa* Ward. ex Engelm. (13%)
Coniferous trees	*Taxodium distichum* L. (4%), *Metasequoia glyptostroboides* Hu & W.C. Cheng (5%)
Deciduous bushes	*Staphylea pinnata* L. (11%), *Sorbaria sorbifolia* 'Sem' (8%), *Salix pentandra* L. (8%)
Perennials	*Gentiana pneumonanthe* L., *Gunnera manicata* L., *Nymphaea alba* L., *Nymphaea candida* L., *Myosotis palustris* 'Bill Baker', *Myosotis palustris* 'Mermaid', *Myosotis sylvatica* 'Blue Basket', *Myosotis sylvatica* 'Ultramarine', *Aruncus dioicus* Walter, *Hepatica nobilis* Mill., *Cortaderia selloana* Schult. and Schult. f., *Calamagrostis × acutiflora* 'Overdam'
Ferns	*Adiantum pedatum* 'Imbricatum', *Gymnocarpium robertianum* Newman, *Phyllitis scolopendrium* 'Crispa', *Onoclea sensibilis* L., *Polystichum braunii* L., *Polypodium vulgare* L., *Matteuccia struthiopteris* L., *Blechnum penna-marina* Poir.
Climbers	*Hederia helix* 'Conglomerata', *Hederia helix* 'Crispy', *Hederia helix* 'Thorndale', *Wisteria chinensis* 'Prolific', *Wisteria floribunda* 'Snow Showers', *Aristolochia manshuriensis* Kom., *Aristolochia macrophylla* Lam., *Clematis alpina* 'Pamela Jackman', *Clematis* 'Henryi', *Clematis* 'Jackmanii', *Clematis* 'White Swan', *Lonicera periclymenum* L.

make walking easier. A side footpath is designed in two forms. The first one is a side branch into the terrain. This will enable watching greenery from another perspective. Elevating the side footpath slightly is another form. It is planned to create a resting place on one of the terraces. Assuming that interference into the existing landscape should be minimised, a timber surface installation is proposed. There will be a small gap between the planks for the grass to grow out. This form of the surface will increase the natural effect and wild character of the area. The entrance for the handicapped should be prepared from the south, in the form of a properly profiled ramp. All surfaces are uniform in style and material. They are the connecting element between individual parts of the garden – rainforest (Fig. 3).

Two forms of benches were planned in the project area. The first one is the benches for resting along the main footpath. They were designed to be as much similar as the footpath surface. Timber was the selected material. A long, ribbon-shaped bench for a bigger number of visitors was planned on the terrace. The project proposes to place two forms of hammocks in "The heart of the jungle": spacious netting between a few trees for several people and a single hammock for one person. Lighting systems in individual areas were designed on the basis of an analysis of the footpath sections. The garden – rainforest project includes installation of technical equipment which, following the correct selection and distribution, shall support the project's objectives. The following elements are proposed: an amplification system (in-

FIGURE 3. The project idea visualisation: A – ramp and waterfall, B – stairs leading to vantage point (own work)

stalling a special audio system consisting of an audio player and speakers distributed in the garden area; the system would play soundtrack with natural bird voices and water sounds), an irrigation system, sprinklers (installation of several sprinklers to imitate drizzle), mist generators (these devices will strongly influence visitors' senses by introducing the wet rainforest climate). The current entrance to the area does not have any representative element and the plan is to create one. The proposal is to create a natural gate in the form of an arched tree (Fig. 4). The exit will also be marked in the form of a natural wooden gate.

Option 0 includes the assumption that no reclamation activities in the quarry area will be implemented. In the event of the lack of any projected activities, the area of the planned garden – rainforest will definitely remain in the degraded condition. One of the environment degradation forms which may occur in the discussed area is soil degradation, which should be understood as any physical, chemical or biological changes of its qualities, which result in considerable worsening of its biological activity and aesthetic landscape qualities. The quarry area would also undergo large ecological succession. In consequence, the existing

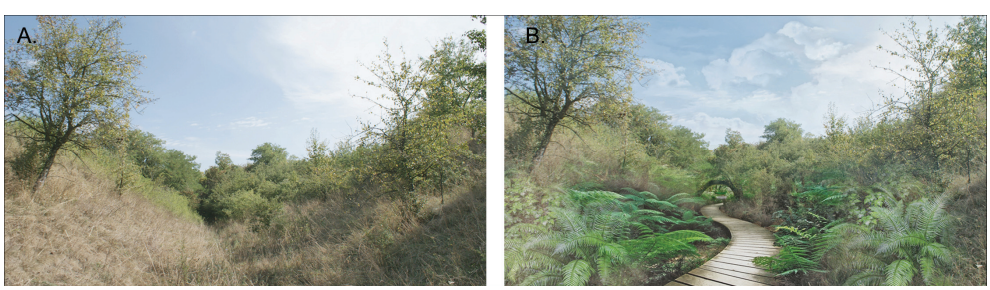

FIGURE 4. Entrance to the rainforest garden: A – current form, B – proposed form (own work)

Discussion of the project solutions

The research work included analysing two options of the discussed area development.

plant species would be replaced. The succession in a given area can be analysed from the perspective of the current plant forms, which create new habitats and

the appearance of other species. Then, the discussed area will become a wasteland. The area without special aesthetic qualities, combined with the appropriate elements, will not be suitable for active and passive recreation. The usable value of the area would not increase due to the continuing degradation process. The existing vegetation could uncontrollably turn into a shapeless form, making it impossible for the inhabitants of Gogolin to visit the area.

Option 1 presents the quarry area as a zone with a new function, which supports regional development. Establishing a botanical garden in Opole province is necessary. Already in 1978, Łukasiewicz stated that the role of such gardens has been increasing; therefore one can observe their dynamic development. Botanical gardens also play an important role in environment protection. They also contribute to increasing social awareness of the protection of endangered and rare species. According to other sources, a botanical garden is an educational centre for people of different age (Müller, 1994; Powledge, 2011). Considering the above it can be stated that every province needs such type of a garden centre. The Botanical Garden in Gogolin is certainly a pertinent project, which can positively influence plant species protection and contribute to regional development.

A botanical garden is also one of the garden forms, which can alleviate difficult living conditions in cities. Green areas considerably improve living conditions. Gogolin is not a large agglomeration but it can be a destination for the inhabitants of the nearby cities, not only from the Opole province (Norton et al., 2016). The project's new area largely adapts the current form of land management. However, in order to meet the requirements of contemporary visitors, certain actions have to be initiated in order to verify the form of the existing area. The main idea of the garden – rainforest project is the most accurate presentation of the equatorial humid forests, taking into consideration the potential of the habitat and climate. Rainforests are specific habitats, still not wholly discovered by man. However, these precious areas have been destroyed by man for years. Considering their current degree of degradation, one may state that rainforest will have ceased to exist in a quarter of a century. Therefore education of the society is of extreme importance. Creating a themed garden inspired by a tropical humid forest offers an opportunity to get to know the beauty of this extraordinary habitat and understand its important role in the whole ecosystem.

Rainforests are a great habitat for numerous plant and animal species. We have not discovered most of them yet, however, the main plant species are, among others: tree forms: *Acalypha* sp., *Bauhina* sp., *Coffea* sp., *Dendrocalamus* sp., *Hevea* sp., *Hibiscus* sp., *Jacobinia* sp., *Plmae* sp.; green plants: *Aglonema* sp., *Coleus* sp., *Filicinae* sp., *Selaginella* sp., *Dissotis* sp., *Musa* sp., *Peperomia* sp.; lianas: *Allamanda* sp., *Aristolochia* sp., *Cissis* sp., *Discorea* sp., *Monstera* sp., *Solanum* sp., *Vanilia* sp., *Vitis* sp.; epiphytes: *Bromeliaceae*, *Epiphyllum* sp., *Phyllocactus* sp., *Rhipsalis* sp., *Liliaceae* (Milliken, Zappi, Sasaki, Hopkins & Pennington, 2010). It is not possible to introduce the above mentioned plant species in the planned themed garden. That is why it is necessary to undertake

other activities, in order to achieve the planned objective. One of the main elements, which make the themed garden in the Opole Botanical Garden similar to rainforest, is the properly selected vegetation. The selection was made on the basis of the habitat qualities as well as individual features of each plant species.

The objective was achieved by the following actions:

1. Introducing the plants with high degree of adaptation to humid environment (deciduous and coniferous trees, deciduous bushes, perennial plants, ferns, climbing plants).
2. Selecting the plants with interesting leaves texture and shape. The selected species of deciduous and coniferous trees may resemble some plant forms common in rainforests, thanks to certain features: *Ailanthus altissima* Mill. – large leaves, *Gleditsia triacanthos* L – large leaves, long pods, thorns, *Sophora japonica* L.: impressive leaves, seed pods in the form of a string of pearls, *Taxodium distichum* L. – characteristic pneumatophores.
3. Introducing a selected quantity of colours, mainly dark green, green, blue, violet and white. The effect is visible on the example of perennial and climbing plants: *Gentiana pneumonanthe* L. – blue-violet flowers, *Nymphaea alba* L., *Nymphaea candida* L. – white flowers, *Myosotis palustris* 'Bill Baker' – blue flowers, *Myosotis palustris* 'Mermaid' – blue flowers, *Myosotis sylvatica* 'Blue Basket' – blue flowers, *Myosotis sylvatica* 'Ultramarine' – blue flowers, *Aruncus dioicus* L. – white flowers, *Hepatica nobilis* Mill. – blue-violet flowers, *Cortaderia selloana* – white flowers, *Clematis alpina* 'Pamela Jackman' – blue flowers, *Clematis* 'Henryi' – white flowers, *Clematis* 'Jackmanii' – violet flowers, *Clematis* 'White Swan' – white flowers.

Conclusions

Developing closed limestone quarries into botanical gardens is an ideal solution for modern towns. Such places have been popular and frequented by visitors. The quarry area has appropriate landscape features, sufficient surface and a rich habitat, which are indispensable for creation of a botanical garden. Creation of a botanical garden shall contribute to protecting valuable habitats and species biodiversity. It also provides *in situ* and *ex situ* species protection. Opening a new tourist and scientific facility shall support creating many new jobs. Apart from the new employment opportunities for the local population, the activity will also promote young landscape architects. Students will gain a new didactic facility and the opportunity to improve their skills in practice. The inspiration of the themed garden with rainforest resulted from the appropriate climate conditions and the habitat available in the area. The area is characterised by humid soils, which can be increased through implementing a number of activities within the project. Additionally, the area has a high percentage of afforestation. By introducing minor changes in the plant species composition, it is possible to obtain the rainforest climate. The final project of the themed garden is a combination of the actual landscape beauty, rainforest

as an inspiration, interesting creative activities and original individual elements, all combined with the correctly selected vegetation.

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Summary

The proposal to transform an old limestone quarry into a botanical garden with a rainforest zone: a case study. Nowadays, a significant part of cities is tackling the problems with post-mining areas. This man-

uscript is an original research which shows possibilities of their reclamation. The aim of the article is to present the proposal of developing the closed limestone quarry and creating a botanical garden. The proposed spatial solutions allow for creating a new, tourist and recreation space, maintaining the natural heritage. The work also assumed carrying out a dendrological inventory, in order to determine the existing dendroflora. The required spatial, nature and communication analyses, which illustrate the current condition of the area and define further design works, have also been carried out. The main idea of the project was to maintain the particular biodiversity, combined with regional culture and its continuous development. This type of assumption aims not only at protection of endangered species. It also has a great role in shaping the awareness of natural environment of various social groups. The creation of a rainforest substitute in the Opole Botanical Garden was possible through selection of the existing afforestation, considering its adaptation as well as through liquidation and introduction of new trees, shrubs, perennial and climbing plants, which shall emphasise the tropical landscape type by their shapes, texture and colours. The project includes many elements, which reflect the general image of humid rainforests. The planned vegetation in connection with the appropriately selected architecture shall undoubtedly influence visitors' senses, transferring them to the 'wild' and mysterious part of the world.

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