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Contaminated Areas as Recreational Places—Exploring the Validity of the Decisions Taken in the Development of Antonia Hill in Ruda Śląska, Poland

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Abstract: This paper describes the experimental developing of a post-zinc industry spoil heap in Ruda Śląska, Silesia (an industrial region of Poland), that was turned into a recreational area. The aim of the present article is to analyse the design process and evaluate its effects. The project in question was meant to be a pilot action of the international one entitled Implementation of Sustainable Land Use in Integrated Environmental Management of Functional Urban Areas—LUMAT, whose Polish part was the Action Plan for the Functional Urban Area of Chorzów, Ruda Śląska and Świętochłowice. The Antonia Hill project involved many aspects and fields of study in order to achieve its aims: limiting the health risk of the Hill's users, maximising the safety of its use as a recreational area, educating its users in the local history and their cultural identity, raising their awareness of the natural environment and its protection. The predominant remediation method was the process described by Loures and Vaz with a modified order of the elements so as to obtain the effect of remediation and development at the same time. The first step was carried out in the form of the site analysis and the potential adaptation possibilities. The next stage was the participatory workshops in the form of Enquiry by Design. The implementation was carried out in accordance with the evidence-based design. The multi-layered structure of the area was built by selecting ideas, activities and goals following the Modelling Nature Method. After the implementation, the facility evaluation process was made by means of the POE method.

Keywords: contaminated area; recreation; reclamation; phytostabilization; phytoremediation; heritage; Nature Modelled; development; design; LUMAT

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1. Introduction

The reclamation of post-industrial areas often applies to contaminated areas of the former dumps of chemical substances, fuels, raw materials, waste-heaps, the areas of factories, steelworks, and others [1]. Upper Silesia provides a few examples of recreational areas located in places contaminated with zinc and lead, but without the proper designed protection of their users from contamination. Dumps with the same contaminants and the same problems to solve can be found worldwide in North Rhine-Westphalia, Germany; Långban Ore District, Sweden; Tipperary County, Munster, Ireland; Smolyan Province, Bulgaria; Picher Field, Cherokee Co., Kansas, USA; Valais, Switzerland; Hamilton, Ontario, Canada, and others [2].

This research presents a critical assessment of solutions used in the Antonia Hill project, which is an example of how to introduce usable functions into an area of high contamination with respect to its cultural and biological identity and how to protect the local people from the toxic material. The condition is, however, that its potential users have to accept the peculiar form of the recreational area. Owing to its contamination, it will not be a typical park with ornamental flower beds, water reservoirs and fountains, or other elements costly to maintain. The design was a pilot project of the international one entitled

Implementation of Sustainable Land Use in Integrated Environmental Management of Functional Urban Areas—LUMAT [3] (Figure 1). The author of the article was the main designer of the Antonia Hill development project.

Figure 1. Partner countries of the LUMAT Program. ● Pilot project location—Ruda Śląska, Upper Silesia, Poland.

The project followed the stages of brownfield redeveloping processes proposed by Loures and Vaz [1], combining the successive phases of the redevelopment into a one-off process. The idea behind the present design was to adapt the area morphology remaining after the heavy industry period and link it with the local "genius loci" by protecting and relating it to the local nature [4]. This assumption follows the Prediction–Adaptation–Resilience approach with its mitigating unfavourable phenomena in the process of the sustainable urban development [5], and the idea of Nature Modelled (NM) [6], with its way of organizing design ideas, making it easier to choose an approach that strengthens local biodiversity and ecological landscape shaping.

The Antonia Hill project was developed with reference to the knowledge of various scientific disciplines, including the issues of remediation of contaminated areas, aesthetics as well as social, historical, and economic conditions. Different ways of reclaiming post-industrial areas for recreational purposes have been discussed extensively in many sources [7–20]. Various contamination remediation methods can be found in [21–39]. Nature-based solutions in development have a large overview [6,19,40].

The most important factor in the Antonia Hill design was the health risk [41–54]. The release of poisonous metal compounds into the soil was discussed in [55–59]. The local geological conditions were provided by [55,60–62].

Spoil heaps have often naturally succeeded primitive green structure or artificial covers of earth layers with similar greenery [63,64]. Such greenery, however, can make a valuable contribution to the decontamination process.

The issues of cultural heritage and its role in sustainable development have been presented in various publications [12,49–70]. The history of the specific place was described in [68,69,71–73]. The local identity present in the reclamation processes was raised in [8,74,75], and the artistic activities related to brownfield were discussed in [65,76–78]. Antonia Hill is a stop on the Post-industrial Ruda Trail going through the brownfield of Ruda Śląska. Similar trails were mentioned in [4,17,74,75].

2. Characterisation of the Study Area

2.1. Preliminary Site Assessment

2.1.1. Historical Context of the Site

Conservation and sustainable management of cultural heritage help the growth and improvement of life quality [66]. Such heritage will bring considerable benefit if the substance in question is definite and visible [12]. What if the heritage remains in the sphere of memory only, or consists of a toxic spoil heap difficult enough to secure, but located near a housing estate whose inhabitants want to relax in the open air? This was the case of Antonia Hill, a post-zinc industry spoil heap in Ruda Śląska. People have interacted with the place for a long time. In 1801 Lazarus III Hanckel von Donnersmarck built the "Antonienhuette" steelworks nearby (named after his wife, Antonia; hence the present name of the site is Antonia Hill). In 1812 the "Hugo" zincworks was opened, followed by the "Liebe-Hoffnung" zincworks in the middle of the 19th century. Their slag was deposited in the area of Antonia Hill [68,69,71–73]. Nowadays it is difficult to find their exact locations. What is left, however, is the spoil heap containing contaminated material, with dangerous steep cliffs a few metres high on the north side. Such places can be hardly regarded as heritage worth preserving, as they require considerable intervention. There are many more of them in Upper Silesia, but they are usually located on the outskirts of cities and do not pose many threats to the local inhabitants (Figure 2).

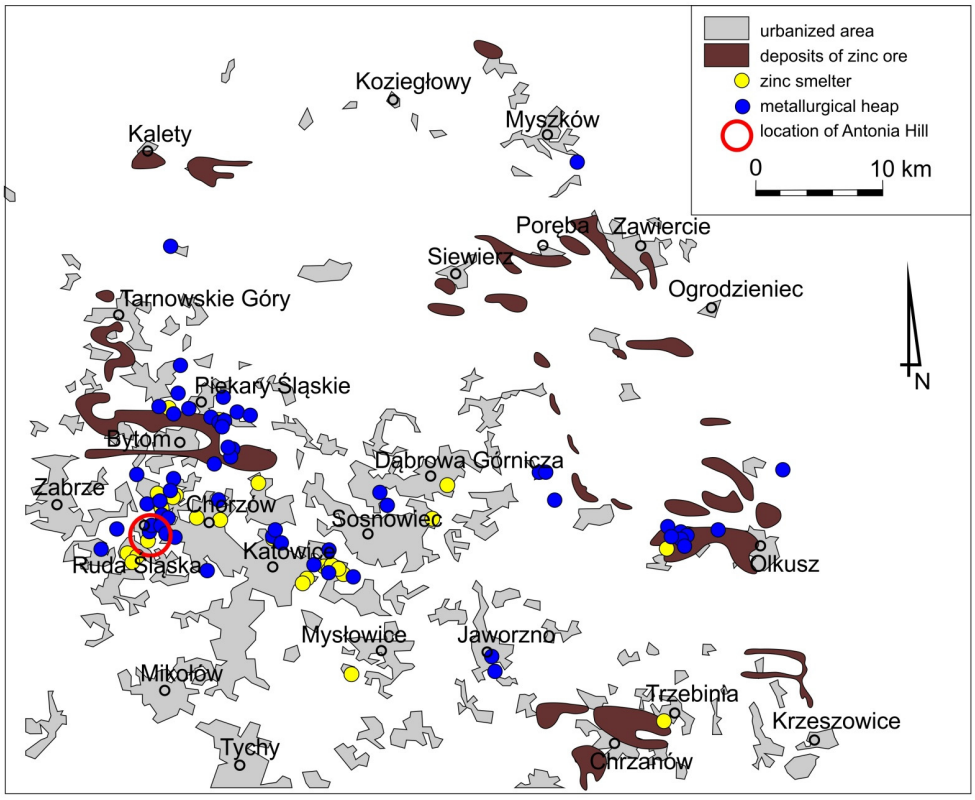

Figure 2. Historical locations of zinc ore deposits, smelters, and metallurgical heaps in Upper Silesia, Poland (compiled after: [49,61,72]).

2.1.2. Chemical Conditions of the Dump

Upper Silesia and Dąbrowski Basin abound in areas contaminated by toxic metals, remains of the former production of silver, lead, and zinc [49,69,71–73]. The mineral used to produce zinc and lead is mainly the dolomite $CaMg(CO_3)_2$, in the form of a blend containing a considerable amount of sphalerite ZnS and galena PbS. Other zinc ores are the effects of sphalerite oxidisation and appear in the form of a blend of zinc carbonates

and silicates. They are accompanied by iron sulphides FeS_2 in the form of marcasite and pyrite, which makes the hue of the zinc ores red and brown [79].

The metal content examinations of Antonia Hill showed the permissible norms to be exceeded (Table 1). However, luckily, there were no radioactive elements exceeding the permissible norms.

Table 1. Contamination level at Antonia Hill (mg/kg) [60,80].

Contaminant	Detected Content	Permissible Content for Parks	Permissible Content for Industrial Area
As	140–3100	25	100
Cd	18–210	2	15
Pb	590–21,000	200	600
Zn	4200–81,000	500	2000

The majority of the chemical processes enabling toxic metals to circulate, release and migrate are in the rhizosphere. Plant roots, fungi, and bacteria are able to initiate those processes by changing the ground chemistry [56–58]. The lowering of the pH content, however, is unprofitable because it is conducive to an increase in the mobility of the cations, especially lead, zinc, cadmium, and arsenic [55]. These elements were considered the most dangerous to human health in Antonia Hill.

The Antonia Hill project made use of the data commissioned for the IETU by the investor in 2016. According to them, the north escarpment of the heap had acidic material, the plateau was neutral, and the south escarpment had alkaline soil (Table 2).

Table 2. Level of pH_{KCl} at Antonia Hill [79,81].

Location	Detected pH
North escarpment	5.27–6.35
Plateau	6.15–7.10
South escarpment	6.90–7.70

The area in question was grown with young pine trees, *Pinus sylvestris*, whose litter of needles acidify the ground nearby [59]. The trees, newly planted, will remain there for some time to make up for the loss of the wood cut in the north part.

2.1.3. Toxic Metal Contamination

Zinc and lead are bio-active metals of toxic interaction with living organisms, including people [42,47–51]. High concentrations of toxic metals have been found in plants [41], insects [82] and mammals [43]. High concentrations, especially of lead, are the cause of many human diseases [51,52,54] The following have been indicated: attention-related behaviour problems, IQ decrements, poorer academic performance, possible puberty delays in older children, renal effects, blood disorders, kidney damage, miscarriages and reproductive disorders as well as significant increase in the risk of cancer.

In order to counteract the hidden danger it is necessary to look for allies in nature. Afforestation, for instance, can play a significant role in the phytoremediation of contaminated soils [29]. The process consists in absorbing contamination by tree tissues [30]. It is related, however, to the sequestration within the plant tissue, mainly the root, but also the leaves, sap, and resin, i.e., the objects that could be touched by the potential users, including children, which may be dangerous for their health. In addition, plants are not indifferent to potentially hazardous element content. In order to survive, efficient support must provided by the presence of microbes, fungi, and bacteria in the rhizosphere [31]. A particularly positive role is played here by mycorrhiza, which was examined in this respect in its relation to *Populus tremula* [32]. This species spreads freely in Antonia Hill. The positive influence of microbes and bacteria in contaminated areas has been well-documented [33]. Observation

of the greenery present in Antonia Hill showed that *Quercus robur, Betula pendula, Sorbus aucuparia,* and *Populus tremula* coped best in these conditions. These species were accepted for planting despite a certain risk of acidification of the soil by oak leaves. The meadows and lawns, however, are to be mowed regularly and the leaves thus removed. The mowing material is to be composted and used for further fertilisation of the land along with lime fertilisers. The post-zinc spoil heaps compost is to be used in the same locations, so as not to transfer the contamination elsewhere, but on indicated spots away from the play area. To reduce the contamination, it will also be mixed with material from other sites and used in other locations.

2.1.4. Flora of the Site

The plants in Antonia Hill belonged to the so-called zinc ore flora or metallophytes. Their representatives are *Silene vulgaris var. angustifolia*, *Armeria elongata var. halleri*, *Biscutella laevigata*, *Cardaminopsis halleri*, *Viola calaminaria*, *Thymus pulegioides* [63,64]. Some of the local plants have a high aesthetic value. To give a few examples, *Thymus pulegioides* with its nice smell, *Festuca ovina* forming tufts of delicate grass, *Cardaminopsis arenosa* blooming white in spring, *Silene vulgaris* blooming later and also forming tufts, *Plantago lanceolata*—a small rosette plant, and *Rumex thyrsiflorus*—a bigger plant with purple fructification. Small, numerous rosettes are produced by *Hieracium pilosella*, forming capitulum inflorescence of a sulphur yellow hue [83]. Because of the high aesthetic value of metallophytes, it was decided to maintain separate fields of these plants on the south slope and to conduct phytoremediation in this area with a gradual reconstruction of the plant composition.

3. Materials and Methods

3.1. Data Sources and Processing

The analysed dataconsist of the following elements: characteristic features of the material deposited on the heap, namely contamination level; carrying capacity of the terrain for the designed roads, hills, and slopes; the land-form and its impact on the users' safety; plant cover; historical values of the site and effects of social participation. The data came from expert opinions commissioned by the municipality, participatory meetings, the present author's site survey and specialist literature. Based on them, it was possible to determine how to manage the heap. Additionally, the range of the development was determined by the project's aims: protecting the local residents from contamination; providing a recreational area; dividing the implementation into phases; recommending a limited amount of greenery and recreational development, introducing educational elements and original objects of small architecture.

3.2. Study Methods

The design process referred to three scientific concepts: development of a contaminated area proposed by Loures and Vaz [1], PAR approach [5] and the idea of Nature Modelled [6], which offers the possibility to preserve the local natural values and genius loci.

The present article discusses the effects of the work implementing the Research by Design method. The subject of the research was Antonia Hill, a post-zinc spoil heap area, creating very difficult development conditions due to its highly contaminated dump material, precipitous cliffs, considerable height differences, and the location in a highly urbanized area. After assessing the conditions, it was decided to design and implement the development project with reference to the scheme of the redevelopment of a contaminated area proposed by Loures and Vaz [1] (Figure 3).

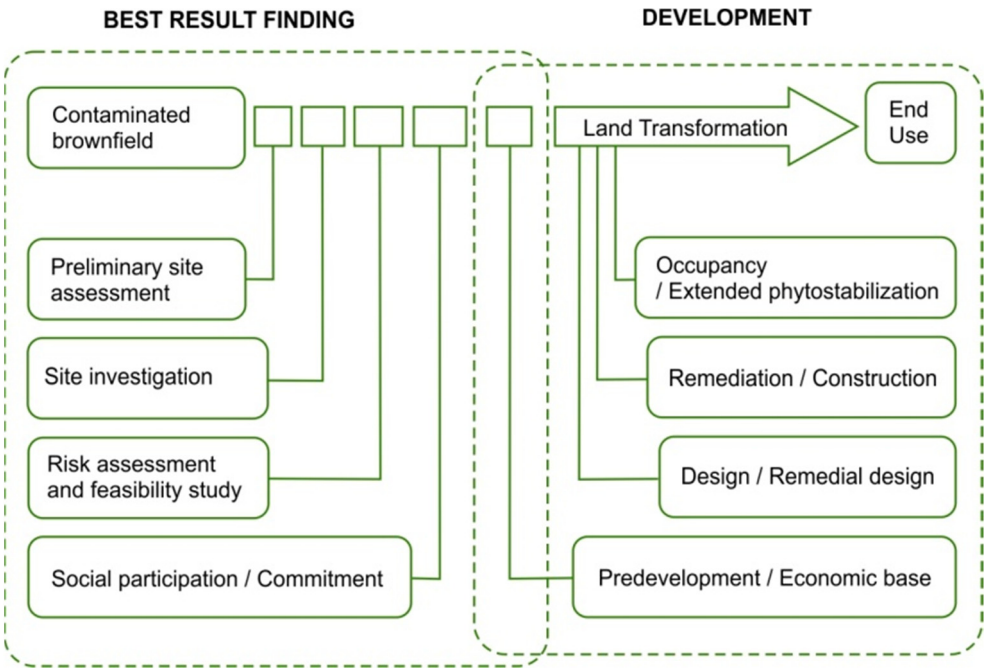

Figure 3. Stages of a contaminated spoil heap development. Adapted from [1] with the change regarding one-stage implementation.

Since the object had significant historical value for the local identity and an original cultural context, it was decided not to blur those features. By applying the Prediction–Adaptation–Resilience approach (Figure 4) the object's potential threats were eliminated, and the area was developed in the form of an open space. Its location enabled linking it with the emerging Ruda Trail, which connects recreational areas in the city [9]. One phase of the predictions was devoted to the considerations on how to solve the post-zinc spoil heap problem. After conducting a risk assessment (Section 3.1.), it turned out that dismantling the whole heap would be possible but expensive and would not solve the problem of contamination for good. Eventually, it was considered optimal to neutralise the risks on the spot. In this phase, public consultations took place and materials obtained from experts were analysed.

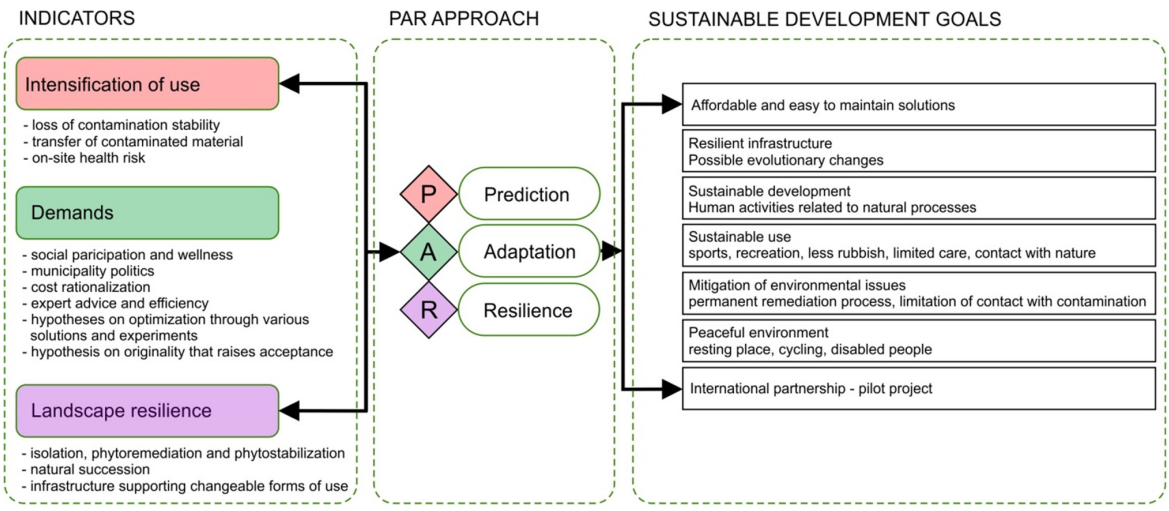

Figure 4. PAR approach concerning urban spatial growth [5] adapted for developing a contaminated spoil heap development.

The Antonia Hill project employed evidence-based design as well. This method entails that while working on a project, expert advice is also used, whereas solutions are arrived at via hypotheses and experiments. The main hypothesis concerned the effectiveness of reclamation achieved by a combination of methods. Accordingly, part of the area was to be left as a natural meadow with metallophytes, allowing active processes of natural succession to occur. Another hypothesis referred to the design of original elements of open space furniture and bicycle infrastructure. Owing to its novelty, the public acceptance is still uncertain.

The adaptation phase was related to the development project. The possibility of contact with the contaminated material was limited, the phytoremediation and phytostabilization processes were initiated, and the area was equipped with the necessary road, lighting, and recreational infrastructure. It is currently in the phase of resilience with increasing services—people learning how to use the area. On the whole, the positive result of the project was that the accessible green area in the district increased by 6.5 ha (=16 acres). The dangerous impact of the industrial period was significantly reduced and its full mitigation is underway. The IETU conducts monitoring and evaluation, which will facilitate the evolution of the development elements in the future.

Nature is always complicated, just like its processes. Thus, our questions remain open: how to act in a world whose rules are not fully known and how to manage space in harmony with nature. Nature and culture are like two distant worlds that we try to combine. The natural world, however, does not create ideal solutions, only optimal ones. We are impressed with the way nature can accomplish its goals. Our attempts to describe them, however, fail because our language is not the language of nature. Our language is extremely simplified, because in order to understand the functioning of things, our minds always need models, ideas—those shadows from Plato's cave. We have no choice but create models to understand what we are doing. Even models, however, can be complex or simplified. The idea of Nature Modelled (NM) describes natural structures from a human point of view, which differs from the standpoint of nature [6]. The models representing this idea are highly developed, so only their general description is given (Table 3).

Table 3. A brief description of the theoretical models included in the Modelling Nature approach adapted from [6].

Model	Goals
The historical and philosophical model	The relationship to nature in the context of the historical duality of being a part of it or being its master
The legal model	Control of activities in the environment and control of the environment itself
The functional model	Nature as a system and our place in it
The formal model	Nature as a source of admirable formal patterns
The perception model	The nature we perceive, how we understand it, how we act in it, how we react to its manifestations
The holistic model	An attempt to describe how nature manifests itself in structures built by man, how we perceive our place in it, how we describe nature to understand it and how we shape nature to ensure that we understand our surroundings; this is the final model of a collection of particular models

To make decisions concerning the project we made use of the holistic model of naturalistic greenery design [6]. This model includes detailed principles of sustainable development in referring to the naturalistic design approach.

Each object has its own conditions. In addition, a group of aims to be realised always depends on the local expectations, possibilities, and the social approval. It is not possible to implement aims that exclude each other or are in conflict, which is also true for complicated ideas like sustainable development. The most important aim is defined in the designing process for a given object. Particular aims must match others and realise their own specific individual path, and not all the paths. Otherwise, the most important one will be blurred. The holistic model mentioned above shows the relations between principles, actions, and their effects (Figure 5).

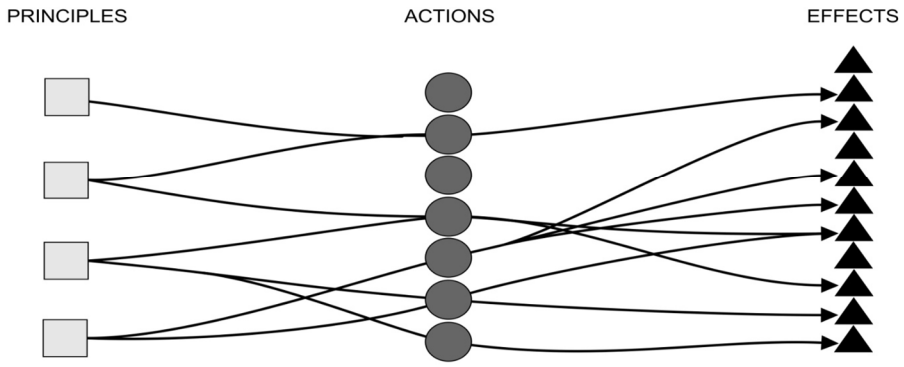

Figure 5. Principles of utilising the holistic model. Each principle can be implemented through different actions, with some of them producing similar effects. It is essential that designers be aware of which principles to implement, which actions to take, and, accordingly, which effects to expect. Particular goals may be considered to be more important than others or less so, depending on the adopted principle. There are always, however, goals that will not be implemented through the applied principle [6].

Basing our design decisions on a holistic model represented a heuristic approach. We did not know all the conditions or all the effects to which our actions will lead, so we created hypotheses concerning the benefit of the project's implementation. We also built the pattern of the design process to achieve the most important goals for the designer and the stakeholders. It was good, however, to understand how many different activities and goals could be chosen from. In the Antonia Hill project, some goals were selected from the holistic model and adopted through the activities outlined below.

3.3. Data Analysis

Applying the Research by Design method, the proposal for implementation was developed considering the following: the risk assessment; consultation during the stages of the project in the process of social participation; adoption of the remediation solutions that take into account biodiversity protection; design of the original elements of small architecture modelled after the industrial structures found in the local steel plant and the coal mine; design of the educational paths, with e programme showing the historical and natural values of the local area. The currently employed POE process [84] is revealing a discrepancy between land use possibilities and social expectations.

4. Results

4.1. Risk Assessment

In the case of Antonia Hill, the local authorities tried to find a way of getting rid of the post-zinc heap. The risk assessment decided the following: its removal to another waste heap would entail the environmental fees of over EUR 250,000, increased by the price of demolition and transportation [60,62]. Its removal to another location would not eliminate the threats but shift them elsewhere. The demolition of the heap would cause considerable dusting that would contaminate the air near the housing estate. The heap material used in asphalt production would involve the demolition of the heap and contamination of the air

for a long time. In addition, the profit made by the asphalt producing firm would be too modest [60].

4.2. Social Participation Process

Contemporary ideas of urban development include the sustainability associated with the participation; the bottom-up, intergenerational approach; complexity and creativity [18]. The participation of the local residents in the land development process was therefore considered crucial [17]. The social participation stage of the Antonia Hill design gave some idea of the needs of the local community, but the number of participants was not sufficient [85]. In the next step, i.e., the implementation of the project, in December 2018, a competition was organised for school students in Ruda Śląska to name the revitalised heap. Their choice was the name "Góra Antonia," in English "Antonia Hill." The problem with the social participation was a low turnout at meetings of 20 people at most. The resulting decisions and the reasons for making them were thus not sufficiently popularised. As a result, many local residents were disappointed with the new green space, where instead of lush greenery they found an interesting but limited proposal that provided permanent protection of the contamination. The ground conditions and the contamination of the post-zinc spoil heap did not allow for free design of rich greenery. Other, safer places were better for recreation. Once, a group of residents decided to have flower beds with ornamental plants without the designer's consent. Most of the plants did not survive longer than a few months, and their action resulted in damage to the insulation layer of the contaminated soil in those places.

4.3. Predevelopment

Securing the heap with clay and soil and setting up a lawn (12,366 m^2) at the cost of 6 EUR/m^2 came to EUR 74,196; phytostabilization (12,266 m^2) at the cost of 3 EUR/m^2 was EUR 36,798, and phytoremediation with a gradual reconstruction of greenery into a protective meadow in places with limited access (17,167 m^2) at the cost of 1 EUR/m^2 was EUR 17,167. According to the cost estimate, the entire investment was EUR 128,161. If the entire area of the site was to be reclaimed by covering it with clay and earth (41,799 m^2), the cost would be EUR 250,794 and increase by nearly 50% [83]. The costs of land levelling, roads, lighting, and small architecture are not included here.

4.4. Design

4.4.1. Remediation and Isolation of the Contaminated Heap Material

Because of contamination Antonia Hill remained a wasteland for many years, despite its location next to housing estates. Brownfield development is usually preceded by a remediation stage. Each stage has its own phases [1]. In the development of Antonia Hill those stages overlapped in order to achieve a safe recreational area in one stage, which is illustrated in Figure 2.

In the area of Antonia Hill three methods of protection were applied: isolating the contaminated material with a protective layer using phytostabilization; stabilising the contamination by means of fertilisers as well as phytostabilization; applying phytoremediation and phytostabilization in an area with limited access. The project used the expert advice of Marta Pogrzeba of the IETU, who suggested the phytostabilization method of choosing plants with minimal absorption of toxic metals in their shoots aboveground, brown coal fraction as sorbent, and lime fertilisers [44–46,86]. The basic types of this kind of grass applied in Antonia Hill were *Lolium perenne* and *Festuca rubra*, whereas *Miscanthus* x *giganteus* served as accents in the form of green screens. The main goal was to provide a safe area for recreation, while minimising the risks from contact with the contaminated ground. Following Marta Pogrzeba's suggestion, in order to limit the migrating of Zn and Pb compounds to plants, the outer layer of the soil of the spoil heap was mixed with soil, sorbent (brown coal), and fertilisers, raising the alkalinity [86]. The results of the experiment will be followed for a few years after the implementation is completed.

The north escarpment of the spoil heap underwent isolation. It was necessary to carry out intensive excavations in order to remove dangerous steep cliffs a few metres high. The area was cleared of trees and profiled to reach the slope of 1:3. A large amount of the heap material were sintered cinders. When stirred by heavy equipment, they would turn into dust easily dispersed by the wind as their particles do not bond and cannot be condensed. In order to prevent that inconvenience, all the north escarpment was covered with a layer of clay to stabilise the surface and a layer of fertile soil for phytostabilization to take effect. That process was initiated by sowing certain species of grasses suggested by Marta Pogrzeba. The present author's own observations of the construction of new roads proved that slopes with a layer of fertile soil alone without a layer of clay are not stable and tend to slide down.

4.4.2. Combining Cultural and Natural Values

The Antonia Hill project (Figure 6) used the naturalistic design principles of the Nature Modelled approach [6]. One of its actions was creating structures combining nature and culture. Accordingly, the designed elements were combined with the preserved, natural collection of metallophytes that were left on the south slope in order to gradually convert the species composition into the phytostabilizing grass. Certain elements of the escarpment were allotted as plant signatures such as those in New Zealand [87]. They were clearly geometrical fields bordered with curbs, without any species composition conversion. Metallophytes often provide beautiful aspects, both aesthetically and aromatically, e.g., *Thymus pulegioides* or *Silene vulgaris.* The decision to preserve the south escarpment in the form of a meadow of metallophytes to be gradually converted resulted from a few factors. The first one was to preserve a part of the area with its unique natural features related to the natural plant succession on the post-zinc spoil heap and by this means to preserve the historical identity of the area. The second one was to preserve a part of the area with trees and bushes so that the redeveloped area was not deprived of tall green plants before the newly planted trees grow sufficiently high. The remaining trees were cleared when removing the dangerous cliffs of post-zinc slag. The third factor was the appearance of the neutral pH, stabilising potentially hazardous compounds (according to IETU measurements). Better insolation conditions helped to produce more biomass, whose decomposition fertilised the soil and raised the pH. The fourth factor was to leave metallophytes and other plants growing locally, thus enabling further phytoremediation.

The principle of imitating the naturalistic structures and processes, according to NM [6], was reflected in the Antonia Hill project by securing the organic character of relations, i.e.,

- creating harmony with the habitat conditions on the south slope;
- securing changeability in time when applying the gradual species composition reconstruction of the south escarpment;
- enabling the transience of the natural succession state and allowing for the action of natural forces in this respect;
- implementing complexity by diversifying agricultural solutions adjusted to the soil conditions as well as proposals for people in recreation, sports, education and ecology, including parts of the area with the undergrowth of metallophytes;
- making free arrangements of greenery related to the location of greenery groups, whose geometrical form emphasises the character of the designed landscape and helps to eliminate the impression of derelict land;
- introducing border fluidity with a gradual transition from lawn through a meadow and a wooded area to a massive local wood;
- planning form dynamism with hidden accents, which encourages penetration of the whole object but is also related to the colour aspects of the greenery changing seasonally;
- designing subtlety of accents in the form of dispersed specimens of various plant species, especially in the area of the south escarpment, which preserves the natural succession.

Figure 6. The Antonia Hill design, Ruda Śląska, Poland.

For the holistic model (NM), it was important to follow the Principle of Perception of naturalistic structures since it recommends the arrangement composition to be built of accents and relations between them, without closing the still frames of specific views. Nature does not create viewpoints, it is a person who sets them. Nature is dynamic, for we are surrounded by changing accents in natural landscapes. The fact that they are accents is because of the proper background. In the Antonia Hill project, geometric groups of trees formed free arrangements against the background of a meadow. Elements of small architecture were placed in different locations so that they did not compete with each other (Figure 7). In addition, the way they could be seen depended on the viewer's location. It was assumed that users would discover the functions of those elements themselves and not necessarily according to the design.

The gravel pits were designed as grill-places with dark basalt gravel, like the slag of the heap, but non-toxic, as they are meant to be food preparing areas. The pits are also used for regular meetings of youth groups.

The arched hammock holders were designed to have a wood-covered surface to sit or lie on them. They have handles at the ends to which the user's own hammock can be tied. There are no hammocks installed permanently since in Upper Silesia it is better to not leave any textile elements outside because of the suspended dust in the air.

A track for riding BMX bikes was also designed in the form of a round circus-like trough. It does not resemble typical bicycle tracks, being a new and different offering on the Ruda Trail—the bicycle path joining all districts of Ruda Śląska.

A priority of the Antonia Hill project was its variety of offerings and its difference from typical forms by following the idea of shaping vague, implicit, and complex forms, thus its similarity to natural structures. Nature can be surprising, allowing the experience of a variety of sensations over relatively short distances; hence, a variety of impressions was another priority of the project represented by the experiences of serial vision and sensory timelines [88], including Humphry Repton's historic rule of "Intricacy" [89].

Figure 7. Original elements of small architecture designed for Antonia Hill: (**a**) The arched benches serving as handles for hammocks or deck chairs; (**b**) the construction resembling blast furnaces; (**c**) the observation boxes; (**d**) the historic smelting vats.

Of course, a post-zinc spoil heap is not the best place for recreation, and parks should rather be located in contamination-free areas that are safe and offer great opportunities for landscaping. The Antonia Hill project's top priority, however, was safety, which was obtained. Although the soil conditions prevented the development of colourful and complex garden forms, efforts were made to gain as much as possible within the strict convention imposed. The recreational area is located on the top layer of the heap. It includes a grass playground surrounded in part by a wide bank of earth. The bank has tunnels made for playing games. The area has a view hill, gravel pits for grill-places, view boxes, and arched benches holding handles for hammocks. There are also low artificial climbing walls with rock textures including zinc ore. The design of small architecture was drawn from heavy industry objects. The observation boxes are of concrete like typical industrial structures. The playground has a construction resembling blast furnaces and coal mine shafts.

This is how natural processes were used in the development while implementing other actions related to creating a naturalistic built-up area (NM). Within that framework the following actions were taken: preferring complexity and adjustment; adapting natural elements; creating structures that referred to natural ones; minimising the energy needed for construction and maintenance; enabling mainly biological self-regulation of a large part

of the spoil heap; promoting native flora; using wasteland for reconstructing local natural values; and stressing the local uniqueness and identity (Figure 8).

(**a**) (**b**)

Figure 8. Fragments of the natural plant cover left to allow the process of natural succession and to contribute to the enrichment of the local flora, also as traces of Antonia Hill's natural history: (**a**) A fragment of the slag cliff with metallophytes as a rock witness to the history of the place; (**b**) the metallophyte spots highlighted by concrete curbs on the south slope.

The locations of the three historic smelting vats in the centre of the site were direct references to the smelting history. The designer's intention was to fill them with earth and plant *Lycium barbarum* with its shoots hanging down, like the sparks of hot metal flown from such vats. Unfortunately, the contractor failed to drill the vats, which were made of very hard alloys. As a consequence, the drainage was impaired and the plants are flooded after rain.

5. Discussion

Degraded areas are commonly treated as potential recreation ones [4,9,12,15]. Post-industrial areas tend to be stigmatised as ugly, dirty places, particularly difficult to revive, often struggling with crime [7].

The attitude towards their reclamation adopts different forms. One approach assumes hiding all traces of their past as something unwelcome. Whereas another approach emphasises those past traces as a manifestation of one's local identity [8,74]. Those areas may also provide a recreational offering with a unique landscape background [75].

Upon examination, the Antonia heap slag demonstrated unsatisfactory condensation conditions, according to the Polish regulations [80] referring to earthworks [62]. In the implementation phase it was confirmed that the material pulverised by the excavations would not provide the required carrying capacity for the designed roads and paths. When constructing a view hill, it was necessary to mix the heap material with a geosynthetic to raise its carrying capacity (the contractor's own technology of active light ash) in order to achieve 1.5 MPa or condensation index Is $\geq$0.95.

Three methods of protection were applied to Antonia Hill: isolating the contaminated material with a protective layer using phytostabilization; stabilising the contamination by means of sorbent and fertilisers as well as phytostabilization; applying phytoremediation and phytostabilization in an area with limited access. These diverse approaches followed the concept of nature-based solutions in development [40]. Being inspired and supported by nature, with their aims of cost-effective development and maintenance, they provided environmental, social, and economic benefits [19]. Generally, the materials used in phytostabilization helped to increase phytoaccumulation, e.g., uncharged zeolites [34] and brown coal [86].

The remediation of contaminated areas required various technical solutions for biostimulation and bio-augmentation [22,23,25–27], among which sorbents, microbiological and enzymatic preparations, chemical substances of natural origin or nanoparticles are worth mentioning. In the case of contamination resulting from toxic metals it was recommended to use cyanobacteria [28]. Also, research has been conducted in the genetic engineering of transgenic microorganisms that can neutralise contamination. Their release, however, into the environment might result in unpredictable consequences. The south escarpment underwent phytoremediation. According to the specialist literature, it is advisable to use fertilisers in order to reduce contamination [35]. In particular, nitrogenous fertilisers are recommended for use in phytoextraction [34,36]. Another possibility of phytoremediation is the application of bacteria and fungi [37,39], which was not used in the case of Antonia Hill.

Generally, publications concerning cultural heritage refer to the remains of buildings and industrial structures. Rarely do they perceive spoil heaps and other waste deposits to be of any value in this context [12]. On the other hand, open post-industrial areas are considered as an interesting background for art and various artistic activities [76–78]. Attention is drawn not only to the tradition of the place but also to its phenomena, that is, its peculiar connotations, making one think of artistic experiences and associations [65]. In this respect, landscape becomes a creative medium in the dialogue between nature and culture. Multi-functionality can also be a paradigm for open areas [70].

Cultural heritage was an important aspect of the Antonia Hill project, following the recommendations of the Faro Convention. From the very beginning Antonia Hill was to become part of a row of recreational objects belonging to the Ruda Trail and the Industrial Monuments Route developed in Upper Silesia. Similar trails were developed in other post-industrial areas [4,17,74,75].

A useful method to apply in the Antonia Hill design was the Prediction–Adaptation–Resilience approach (PAR). It helped organise the method of adapting post-industrial areas and resulted in achieving the aims of sustainable development [5]. This approach allows changes of the urban structure, as well as projection of the city centres' condensation or growth of the urban sprawl. It also suggests mitigation methods of any phenomena unfavourable to sustainable development. In the case of Antonia Hill, the improvements involved its space quality and the recreational and natural functionalities, thus creating conditions conducive to keeping people in the city centre. On the whole, reaching Sustainable Development Goals enables towns to become more affordable, safe, and liveable [10,11,13,20].

Future research on Antonia Hill should demonstrate how the phytostabilization and phytoremediation processes are progressing. There are also no permanent solutions to the recreational infrastructure of the area. The POE research [84] should answer the following questions: whether the users have accepted the aesthetics of Antonia Hill, whether the durability of the elements of small architecture is sufficient, whether the information on educational boards is still useful or should it be changed from time to time, whether the massiveness of the elements of small architecture protects them from vandalism. It is also important whether phytostabilization by means of the local vegetation, allowing the process of natural succession, will contribute to the enrichment of the local flora. Areas with similar contaminations can surprisingly become habitats for rare, protected plants [90].

After initial observations it was possible to formulate several conclusions: lack of flowerbeds, noticed by some users, could be solved by geometric fields of selected metallophytes of the highest aesthetic value; too much reverberation inside the observation boxes should be mitigated by the inner surface of their walls; the structure on the playground, which unexpectedly served young people as a difficult climbing wall, must be readjusted by securing the trusses crowning the towers to prevent getting stuck in them; because some paths are steep and difficult use, especially when covered with frozen snow in winter, it will be necessary to build side barriers to assist walkers, as steps cannot be built because the area must be accessible to technical service vehicles; two extreme paths with a surface

of broken gravel bonded with epoxy resin turned out to be slippery in rain immediately after construction since the sharp edges of the stones were considerably softened by the resin, but now they are slowly wearing down, which increases the adhesion of their surface; some of the trees planted and the proposed miscanthus did not survive because in these soil conditions they required much more frequent watering than was usually done, so the upkeep design should include larger amounts of watering.

The progress and effects of the LUMAT project can be followed on the website of the IETU, the leading partner of the program [3].

6. Conclusions

The implementation of the Antonia Hill project led to the protection of the toxic dump within reasonable costs, which inspired the foreign LUMAT partners to carry out similar projects in their countries [3].

The use of the three reclamation methods, i.e., the isolation of toxic material with tight soil layers, the phytostabilization, and the gradual phytoremediation in places with limited access, with the assumed stimulated plant succession, reduced the cost of the complete rehabilitation of the study site by 50%. This confirmed the correctness of differentiating the approach even within one facility.

The phytostabilization method applied was an experiment conducted by the IETU employees and served as a scientific assessment of the effectiveness of the actions taken on the top of the heap. The following years will show whether the adapted methods are effective and what differences they make.

Antonia Hill's reclamation contributed to the expansion of the recreational areas in the Czarny Las district in Ruda Śląska by 6.5 ha (16 acres).

The quality of local open space increased with the Antonia Hill development. The implementation of the educational paths with their local historical, geological, and natural values as well as the elements of original and recognisable small architecture especially designed for that particular place promoted Land Art forms and situated art in a historical context.

The LUMAT partners were inspired by the principle of creating sustainable space with all its local connotations and means of education that related to many local values. The originality of the implemented elements of development and the reduction of the typical elements was an attempt to counteract globalisation and conform to the assumptions of the European Landscape Convention.

The implementation of the Antonia Hill project proved that it is possible to reclaim a toxic heap without expensive flower beds, with simple measures that are easy to maintain. The reclaimed heap is an attractive place for many people who come to the area once considered irretrievably lost in order to run, walk with prams and pets, meet after lessons, and ride sledges.

The public consultations phase with its low turnout caused some problems. After the project's implementation, the residents wanted to improve the quality of the green area themselves, without the designer's consent. They planted a flowerbed of unsuitable plants, most of which died in the same season and disturbed the protective layer of the heap. Despite many information boards, the local community at times does not understand the great danger hidden in the heap. Time will tell whether their awareness of the problem increases, or the dream of their Garden of Eden prevails and the problem of contamination reappears once more.

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