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Economic Optimization of Urban Mining

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Abstract: This paper presents a general approach when performing urban mining activities. The urban mining concept is a necessity when the Mega cities increase in numbers to create attractive, sustainable cities for modern people. There are veins of precious minerals that are richer than any goldmine, running through our cities. The equality principle is applied on urban mining in order to simultaneously optimize the economy, the technology used and the environmental conditions in general. Shadow costs are employed to give economic incentives to improve the current urban mining activities. A versatile key factor is introduced that provides management with a tool to immediately obtain a general status report of their urban mining project. A Swedish office block is the object of a case study. Thereby, special focus is on the least important fractions with a positive value from an economic point of view that are intended to be optimized. The introduced approach shows utility and the model for Efficient Use of Resources for Optimal Production Economy (EUROPE) gives reasonable results when applying the equality principle on urban mining business. The major benefit with this study is the introduction of a novel method to improve urban mining projects of all kinds featuring conversion of all technical and environmental aspects of a project into all-embracing monetary measures. It is recommended to apply the equality principle and its mathematical expression, the EUROPE model, on recycling activities in general and particularly on urban mining projects.

INTRODUCTION

The urban mining concept is a necessity to create attractive, sustainable cities for modern people who demand healthy dwellings. Modern architecture must create an advanced infrastructure with good communications and a clean environment when the Mega cities increase in numbers. This paper presents a novel approach to urban mining activities that is considered to be generally applicable.

Practicing of urban mining is a necessity since mining virgin resources deep down in the ground is becoming ever more expensive. Today, there are more raw materials accumulated in houses and infrastructure than what is possible to mine by using traditional methods. There are veins of precious minerals that are richer than any goldmine, running through our cities [1].

The world's population will grow to 9 billion over the next 50 years [2]. Also this rapid development calls for the efficient utilization of already mined natural resources.

Due to human activity, finite resource-stocks in the technosphere grow continuously at the expense of decreasing in-ground deposits. In other words, human activities change the prerequisites for mineral extraction. Thus, mining activities are likely adapted accordingly. In doing so, more emphasis would be on the exploitation of previously extracted minerals [3].

Large technical systems serve the everyday needs of people. In order to remain efficient and modern, these systems must be redesigned, rebuilt and new-constructed to be energy-efficient and environmental friendly. Such systems are rich in accumulated metals, examples being water supply systems, power grids or communication networks and other construction materials. Now and then

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parts of these systems are taken out of use. Then the system infrastructure is not removed from its original location and is hence suitable for application of urban mining technology. Such hibernated metal stocks constitute potential resource reservoirs which can be the object for recovery activities [4].

Brunner [5] states that metal recycling plants combined with utilization of waste energy from such plants are an option to make cities more sustainable. In particular, this approach is viable for fuelling of a city's electric, heating and cooling requirements. As regards urban mining, data about flows and stocks of materials and substances are important.

In recent years, research groups have been established themselves in the for research area of urban mining with significant contributions; based on their research activities, several active members in urban mining are identified such as Hogland *et al.* [6], Krook [7] Krook and Bass [8] and Krook *et al.* [4]. Lately, cities have been considered as landfills or city dumps. Usually, the ground underneath the cities is heavily polluted and the sewage as well as the drinking water systems and ground water resources are contaminated with toxic pollutants.

A major problem is that developed countries have more control of existing materials and chemical substances in the landfills than what they have existing data information for urban areas. This is very problematic indeed as regards the societal resource-flow, also when reconstructing urban areas.

Krook and Bass [8] claimed that urban mining and landfill mining have a high potential but the state-of-the-art is theoretical. This implies a need to study applied approaches that can be used to develop practically applicable methods and hands-on technology to enable assessment of the practical performance of these activities. Thus, the novel model introduced in this work to optimize urban mining activities fills a scientific and practical gap while providing a versatile tool in practice to improve urban mining projects by employing economic incentives to do so.

As regards other recent works on urban mining, Bacci and Diniz [9] have studied mining in urban areas in order to identify and mediate socio-environmental conflicts. As regards the technical aspects, Di Maria *et al.* [10] have studied the quality and quantity of recyclable and recoverable material that is mechanically and physically extractable from residual waste when performing urban mining. Wallsten [11] has examined the subsurface infrastructure in Swedish city Norrköping from an urban mining perspective with focus on iron, copper and aluminium that exist in large quantities in infrastructure parts. Wallsten [11] hence regards the built environment to be a resource-base for materials. Wallsten *et al.* [12] have also looked at the prospect of an urban mine to assess the metal recovery potential of infrastructure "cold spots" in Norrköping, Sweden. Kwon *et al.* [13] have studied the urban energy mining aspect. Thereby, they showed that sewage sludge could be a strong candidate for biodiesel production. Cossu [14] has in general described the urban mining concept while Krook [7] has approached the urban and landfill mining phenomena in a global perspective.

However, no attempts were made earlier to just one key factor, such as the one defined by equation 10 that is as a cost structure for economic optimization of urban mining discussed in this work. This paper expresses the general condition of a certain urban mining project. It is usually advantageous and simplifying for management to study just one encompassing key figure to obtain an immediate understanding of the general status of an urban mining project. The approach introduced in this work enables that while in the same time providing a versatile tool for management to review, monitor and evaluate their endeavours in order to simultaneously optimize the economy, the technological level of the equipment used and the environmental status in general.

Jones *et al.* [15] introduced the concept of enhanced landfill mining, defined as the safe condition, excavation and integrated valorisation of landfilled waste streams as materials and energy, using innovative transformation technologies and respecting the most stringent social and ecological criteria. The reason for this innovation was that the past landfill mining was not performed with a focus on resource recovery.

In the European Union, the concept of Zero Waste management [16] denotes the European authorities' ambition to improve the daily waste management situation. Hogland *et al.* [17] have introduced the principle of Enhanced Zero Waste which stands for the ambition to bring back all artificial waste streams produced since the industrial revolution to the current anthropogenic circuits.

In this paper, the later developed concept of Beyond Zero Waste is expressed by adapting the first author's innovation, the EUROPE model. This model is implemented for the urban mining context in order to encourage the recovery of all materials lost during the entire life cycles of different products that are manufactured, which are still available in different sinks such as landfills, sediments of rivers and oceans.

Thereby, the ambition is to provide managers with practically useful tools that give economic incentives to reduce the wastes at the sources and re-direct the waste streams to the current anthropogenic loops in a way that enables monitoring and evaluation of the on-going urban mining projects as well as stimulate reconstruction and new building earlier than traditionally.

The Ultimate Zero Waste concept is the uttermost method to handle wastes. This novel concept that here is developed and introduced by the authors encourages recovery of virtually all materials lost during the entire life cycles of different products ever manufactured, still available in different sinks such as landfills and sediments of rivers and oceans, etcetera.

All waste, materials and chemical compounds lost, such as sludge, slag, harbour sediments and others can, in principle, return to the anthropogenic loops. By implementation of the Ultimate Zero Waste concept, the toxic substances could be removed from the current ecological circuits and hence can be handled in an environmental-friendly way.

The long-term goal is to apply this extreme but innovative approach in an efficient way in environmental and economic terms. Thereby, the accumulated knowledge, including know-how of reuse and/or recycling of materials bound in urban and rural structures is considered and applied in practice. This paper promotes that ambition by employing the EUROPE model in a novel way as a complement to the previous areas of its application.

The present paper hence offers a novel concept for how to improve the waste management situation in cities with emphasis on the recovery, recirculation and recycling encompassed in the term urban mining. Thereby, special focus is on such fractions that show least profitability among those having a positive economic value on the scrap market.

MATERIALS AND METHODS

In this paper, the EUROPE model based on the equality principle is introduced for the specific purpose of in general optimizing the urban mining activities featuring economic incentives as the tool for achieving an improved recycling and recirculation of residuals in the city environment. In doing so, an introduction describes the peculiarities of urban mining and reviews the research frontline of this phenomenon.

Next, the basics of the EUROPE model are outlined as the basis for the following development of the cost structure that is proposed to solve the problem of how to optimize the urban mining activities locally as well as globally. The findings in this section constitute the foundation for the case study that follows wherein the EUROPE model is applied in practice employing real world data.

Thereafter, the major results are presented and discussed. Finally, conclusions are drawn, the benefits from the current research are outlined and recommendations are given for how to apply the findings presented here. Suggestions for further research are also given.

The chosen scientific methodology is a combination of the study of: (a) what common practices as regards mainly the economic studying of the urban mining phenomenon should be changed and how and; (b) the development of theories and models, in this case intended for application on urban mining activities, based on knowledge presented in a scientific paper. The main scientific approach is analytic.

To a large extent, a quantitative methodology is applied. The theory is exemplified with numerical examples from an office block in Sweden. The input data for the case study is extracted from a study by Brick [18]. For prices and costs, an exchange rate of nine Swedish Crowns (SEK) is equal to one Euro (EUR) is applied throughout when performing the calculations.

In this work, "residuals" are defined according to ISWA as: "material left after treatment processes, e. g. combination of wastes…" [19]; while, according to IEA, one possible definition among many other of "urban residues" are: "wood materials from urban areas, such as newspapers, lumber and plywood from building demolition and used packaging and shipping wood materials" [20]. In this work, "urban mining" is defined by the authors as meaning the recovery of materials and compounds of commercial interest from daily generated waste, existing urban constructions plus substances that throughout history have escaped from the anthropogenic, closed loops and circuits. This new definition constitutes an extension and a specification of the established definitions given by Stallone [1] stating that urban mining is "the process of reclaiming compounds and elements from products, buildings and waste" and as defined by Yahaya *et al.* [21] who emphasizes that "gold also can be extracted from electronic waste or e-waste" and this is called urban mining.

Cost-benefit analysis (CBA) is defined as a technique which attempts to set out and evaluate the social cost and calculate the social benefits of investment projects to help to decide whether or not a project should be undertaken.

The essential difference between CBA and ordinary investment appraisal methods used by firms is the stress on the social costs and benefits. Thereby, the aim is to identify and measure the losses and gains in economic welfare which are incurred by society as a whole if the particular project in question is undertaken [22].

Thus, CBA is considered to be suitable for encapsulating the majority of the different cost items, also intangibles, that is relevant to consider when evaluating the monetary impact of a project. In this paper, a modified CBA approach is employed in order to estimate the impact of diverse urban mining endeavours expressed in all-encompassing monetary terms which hence to a certain extent regard also social effects.

The validity of the developed methods is promoted by the application of traditional economic theory based on well-known scientific results and an extensive experience of its practical usage. The reliability is strengthened by the use of relevant standard works and peer reviewed scientific papers to support the current findings. Also, the usage of real-world data in the case study reinforces the reliability of the results.

EUROPE Model: The EUROPE model [23] is the mathematical expression of the equality principle [24] which means equalization of residuals with regular products in strictly economic terms. In mathematical terms, this is expressed by putting both the total, regular output of goods and the total output of residuals in the denominator in Equation (1).

$$PF = A / (B + C) \qquad (1)$$

Where PF is the proportionality factor to be multiplied with the total cost (TC); A is the waste fraction to be optimized, the "bad" of specific interest; B is the total output of regular products, the total "goods" and C is the total output of residuals, the total "bads" within a certain administrative unit and time-period. The unit may sorts in kilo, litre, Joule or a currency.

PF is multiplied with the total cost (TC) of the administrative unit that is studied. This gives a so called shadow price or shadow cost that does not exist in reality but if taken for real provides economic incentives to improve the urban mining by reducing the occurrence of the unwanted residuals. These shadow costs also enable monitoring and evaluation of the general status of the urban mining projects. The less the shadow costs is, the better the organization in question namely has become to handle the residuals also from an environmental point of view.

The cost structure for economic optimization of urban mining: Urban mining means handling many different waste-fractions at the same time. In the numerator of Equation (1) this is expressed by employing a sum as shown in Equation (2).

$A = \sum A_i =$ the sum of the n different waste fractions to be optimized $\qquad (2)$

$i = 1,…, n$ where $n > 0$ (integer) $\qquad (3)$

Sort: kilogram, litre, Joule, currency etcetera.

Generally, A denotes such materials that with today's recovery and extraction methods cannot be taken care of in an economically feasible way.

In the denominator, the multitude of considered fractions is expressed by the following sum of:

$C = \sum C_k =$ the sum of the in total l different residuals, the total "bads" $\qquad (4)$

$k = 1,…,l$ where $l > 0$ (integer) $\qquad (5)$

Sort: kilogram, litre, Joule, currency etcetera.

Generally, C denotes the second order of residuals that can be recovered to a higher cost or with help of advanced recovery methods and/or the third order of residual fractions that commercially can be recovered in the future. B, the other term in the denominator, denotes in the urban mining context the collocated "goods". Generally, B denotes the first order of residual fraction that has the best economic value to the lowest waste management cost or can be commercialized with the easiest method.

$B = \sum B_j =$ the summarized m regular products produced together with $\sum A_i$ and $\sum C_k$ $\qquad (6)$

$j = 1,…, m$, where $m > 0$ (integer) $\qquad (7)$

Sort: kilogram, litre, Joule, currency etcetera.

A common, logical administrative framework to apply equations 1-7 on is chosen.

Summarized, the case of many different waste-fractions is expressed in Equation (8).

$$PF_x = [\sum A_i / (\sum B_j + \sum C_k)] * EIF_x * RRF_x * GWF_x \qquad (8)$$

when $i = 1,…, n, j = 1,…, m, k = 1,…,l$ and $n > 0, m > 0, l > 0$ (integers) $\qquad (9)$

where PF $_x$ is the proportionality factor for the whole waste management scenario considered to be multiplied with TC_x for the current urban mining project x of interest to obtain the cost that should burden the n different waste fractions in A in order to achieve an economic incentive to optimize the extraction of primarily the n components in A. Compare to Equation (10).

EIF $_x$ is the Environmental Impact Factor (sort less) for the object of urban mining in question considers the project's impact on its surroundings as compared to other objects in its own category as regards the actual pollution of air, soil and water which affects the size of the employed shadow costs. An *EIF* of 1.0 represents the average urban mining object in these aspects and is the standard value.

RRF $_x$ is the Relative Representativeness Factor (sort less) for the object of urban mining in question considers the project's representativeness as compared to other objects in its own category as regards the object's geographical and social position in the neighbourhood and its availability for demolition which affects the size of the employed shadow costs. A *RRF* of 1.0 represents the average urban mining object in these aspects and is the standard value.

GWF $_x$ is the General Weight Factor (sort less) for the object of urban mining in question considers the project's relative importance in financial and technological terms as compared to similar objects in the eyes of, for example, project engineers at construction contractors which estimate the project costs to give bids or civil servants at the local municipal offices of urban planning and building which may use the introduced method as a part of the decision basis for demolition and exploitation allowances. A *GWF* of 1.0 represents the average urban mining object in these aspects and is the standard value.

The actual values of *EIF*, *RRF* and *GWF* to be used, for example, could be obtained via public statistics or the private companies' internal databases. Alternatively, the values of these factors are set based on the extensive experience by skilful professionals in the industrial branch in question.

By employing Equation (10) a so called shadow price or shadow cost (*SC*) is hence obtained that, if taken seriously, burdens the accounts of the urban mining project x. Thereby, the management of x is provided with a tool that increases the economic incentives to make the urban mining activities more cost effective and in the same time allows the managers of x to monitor, review and evaluate this process in order to step by step make it more efficient by optimizing the different fractions in order of declining relevance.

Table 1: Materials in a Swedish office block in order of declining value [18]. A negative value denotes a cost. EUR 1 = SEK9.

Material	Amount (tonne)	Value (EUR/tonne)	Value (kEUR)
Copper scrap	26	3330	87
Stainless steel	0.2	780	0
Aluminium scrap	8	440	4
Zink scrap	2	440	1
Galvanized steel	2	110	0
Galvanized steel plate	47	110	5
Steel scrap	927	110	102
PE/PP	5	22	0
Asphalt	14	0	0
PVC	0.3	0	0
Chipboard	5	-6	0
Lightweight concrete blocks	38	-6	0
Plaster	214	-6	-1
Plywood	29	-6	0
Porcelain and tile	20	-6	0
Wood	34	-6	0
Concrete	16 353	-8	-131
Gravel or stone	19	-11	0
Sand, gravel	110	-11	-1
Garden waste	101	-30	-3
Gypsum	214	-70	-15
Glass wool	35	-110	-4
Rock wool	366	-110	-40
Water-based paint	4	-280	-1
Solvent-based paint	1	-500	-1
Total	18 574.5		2

$$SC_x = PF_x * TC_x = \left[\Sigma\, A_i / \left(\Sigma\, B_j + \Sigma\, C_k \right) \right]$$
$$* EIF_x * RRF_x * GWF_x * TC_x \qquad (10)$$

The obtained shadow costs are to be used as a flexible tool to optimize the urban mining project x by throughout influencing the economic system and the daily decisions of the actor in question.

Case Study: Recycling of an office block: A Swedish office block with two connected buildings is the object of study. Numerical examples are taken from a Master's thesis by Brick [18]. The underground floors 1 and 2 contain the garage and a laboratory while floor 3-7 contains the offices. In total, the gross building area is 23,005 m^2 of which 15,717 m^2 is used. The whole surrounding area is 21,500 m^2.

The materials with the current quantities for the block are listed in Table 1.

Equation (8) is applied. *A* consists of aluminium scrap and zinc scrap, the least important fractions with a positive value from an economic point of view, that are intended to be optimized. *B* denotes all the materials with a positive value on the market while *C* is made up of the absolute value of the rest of the residual materials. TC_{case} for demolishing the house and fractionating it in a shredder is estimated to MEUR1 (Jönsson, personal communication, 2014).

The EIF_{case} is set to be 0.9, the RRF_{case} is set to be 1.1 and the GWF_{case} is set to be 1.0 after a qualified estimation by the authors based on their extensive professional experience.

$$PF_{case}(k€) = [(4+1) / ((87+4+1+5+102) + ((-1) * (-1-131-1-3-15-4-40-1-1)))]$$

$$* 0.9 * 1.1 * 1.0 = \left[5 / (199 + 197)\right]$$

$$* 0.99 = 0.0125 = \text{approx. 1\% Compare Table 1 and Eq. } (8)$$

$$(11)$$

$$SC_{case} = PF_{case} * TC_{case} = 1\% * M€1 = k€10 \quad \text{Compare Eq. } (10)$$

$$(12)$$

DISCUSSION

The presented study shows utility when applying the equality principle on the urban mining business. The relevance and the reliability of the conducted research is considered to be good since the case study produces reasonable results pointing at a good general usefulness.

In practice, the resulting shadow cost of kEUR10 is intended to be allocated to the aluminium scrap and zinc scrap fractions of interest in the case study by burdening the estimations, budgets and, by time, the profit and loss account of the company that employs the EUROPE model so to obtain an economic incentive to improve the recycling activities. Also, the introduced methodology is useful as a versatile tool to obtain a relevant decision basis for public authorities such as municipal planning and building committees which grant allowances to demolish and construct houses, roads and bridges etcetera based on the investigations made by town planning offices.

Thereby, companies as well as authorities can study the development over time of the size of the shadow costs that occurs for different projects when the EUROPE model

is used to decide what actions to be taken in order to improve the project's profitability and increase the compliance with rules and regulations respectively. In doing so, a reduction of the shadow costs over time means an improved economy for a contractor due to better utilisation of the resources while a public planning and building office may look at an estimation of the expected shadow costs for a project as described in, for example, an application for demolition followed by urban mining activities as a part of the process for allowing or rejecting a certain request to proceed with an urban mining endeavour or continuously monitor it. Thus, it is concluded that fictive shadow costs are useful to optimize urban mining projects, if these shadow costs are taken seriously to also achieve a tool for measuring how the project improves since decreasing shadow costs mean a more efficient business as regards a better usage of material and energy resources from an economic, a technological and an environmental point of view.

Also, the choice of aluminium scrap and zinc scrap, the least important fractions with a positive value from an economic point of view in the current case study, to be optimized can be questioned. Due to their higher value per unit on the scrap market, metals such as copper and steel are much more rewarding to extract.

However, aluminium scrap and zinc scrap are chosen to exemplify the proposed methodology since they are least profitable among the fractions occurring in the case study of this paper and which have a positive value from an economic point of view. Thus, those fractions are most likely to be difficult to commercialize by employment of the equality principle on an urban mining project. The fact that the application of the theory on also these fractions with lesser relative economic value is proven successful, points in the direction of the presented approach being generally useful.

A versatile key factor in the form of Equation (10) is introduced. This expression provides management and the public authorities with a tool to immediately obtain a general status report of their urban mining project as an all-embracing shadow cost that is fictive but useful in order to optimize a project.

The equality principle has hence been shown to be useful also for urban mining purposes. This principle is likely to improve such activities also on a larger geographical scale than the office blocks in the presented case study, such as a single suburb or a whole city.

Therefore, suggestions for further research are to study how to apply the proposed model on an entire city in order to obtain an indication on which whole parts of

the city to refurbish, similar to when all the fluorescent light bulbs, also the well-functioning, are changed simultaneously in an industrial plant. Thereby, it can be possible to grind, for example, the concrete on site so to make new floors and walls without having to transport the material away from the demolition-site to be recycled. Studies should hence be performed on how to mathematically modify the EUROPE model to enable optimization of such activities from an economic, a technological and an environmental point of view and measure it. Finally, a more ground-breaking approach would be to develop an equation system that focuses on the recycled waste fractions in order to make them becoming almost non-existent. In this way the model presented here could be renewed and modernized which possibly could lead to a brand new basic model for waste management.

CONCLUSIONS AND RECOMMENDATIONS

It is concluded that the EUROPE model gives reasonable results for the resulting shadow costs in relation to the total cost mass of the study object and can be used to improve the economy, the technology and the environment when applied on urban mining. This general conclusion is namely reinforced by the realistic outcome of the conducted case study that more precisely gives a rather realistic shadow cost of kEUR10, in comparison to the TC_{case} for demolishing the house and fractionating it in a shredder estimated to MEUR1, to be used as a versatile tool to optimize the recycling of the office block in question and to monitor, review and evaluate the performance of the project.

The major benefits with this study are the introduction of a method to improve urban mining projects of all kinds by using the EUROPE model in a modified way and the introduction of a key factor that immediately gives corporate management and the local planning and building authorities an overall view of the performance of their current urban mining project. Also, the findings are beneficial for increasing the recycling rate and for shortening of the time period for the reconstruction of a house block or a town district. These features are found to be a novelty.

The major strength of the proposed model is its promising versatility featuring conversion of all technical and environmental aspects of a project into monetary measures, for example, Euros that are virtually all-embracing. Thus, the model provides an emotionally neutral tool which is not biased as regards, for example, ideological aspects of technology usage that sometimes may cause irrational public attitudes against technological projects such as urban mining activities.

It is recommended to apply the equality principle and its mathematical expression, the EUROPE model, on recycling activities in general and in particular on urban mining projects. Thereby, the characteristics of the projects including their environmental consequences are preferably expressed in monetary terms so to obtain a unit for calculations that is neutral in terms of valuations and the technology used.

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Persian Abstract

چکیده

این مقاله کلیاتی از عملیات بازیافت شهری از بستر محل دفن زباله را بحث می کند. محل دفن زباله کلان شهرها نیاز به بازیافت مواد معدنی با ارزش داشته تا تداوم حیات شهرهای مدرن حفظ شود. باید مواد با ارزش این منابع غنی از مواد معدنی نظیر معادن طلا استخراج و بازیافت گردند.

جوانب کار باید مورد ارزیابی قرار گیرد. هزینه ها همیشه بر تکنیک انجام کار باز یافت مواد سایه انداخته است که تحلیل اقتصادی ضرورت دارد. مدیریت پسماند می تواند با گزارش از منابع موجود باز یافت مواد مطلوبی داشته باشد. بعنوان مثال یک بلوک ساختمانی در سوئد را مورد مطالعه و بررسی قرارداده ایم. با توجه به ارزش اقتصادی مواد بازیافت می توان تحلیل اقتصادی برای اجرا عملیات داشت و روش بهینه را معرفی نمود. برای اینکار ابتدا باید مدلی را برای استفاده بهینه از منابع مواد موجود بنام مدل EUROPE برای بازیافت مواد معرفی نمود و با استفاده از روش منابع به روند کار بهبود بخشید و روش اجرا طبق مدل ارائه شده عمل نمود. برای بازیافت مواد ذی قیمت از زباله شهری باید پروژه استفاده از منابع باز یافت را رونق بخشید.