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LIFE CYCLE ASSESSMENT OF FLOORS FOR THE FOOD INDUSTRY

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Abstract

For the purposes of this research, floors on the basis of concrete, asphalt and dry-shakes have been selected from a whole range of different aspects. This constricted selection of three types of industrial floors has been chosen from the aspect of a more detailed analysis of these three kinds. The reason is that if we compared a greater number of industrial floors, we would not achieve such a great and detailed analysis as in this case. Three types of industrial floors have been chosen which are generally considered by manufacturing firms to be the most used and the most sold. In the past and at present, concrete and asphalt floors have been much used, especially in agricultural premises due to their undemanding character and relatively low purchase price. The dry-shakes have been chosen in view of the fact that they are much used and that they rank among the types of industrial floors with a long service life with respect to the rate of input costs, which is the top priority for the food industry.

In view of the fact that the concept of "industrial floors" can be understood from many points of view, it is necessary to specify and define certain research criteria to be applied in the life cycle analysis (LCA).

Key words

LCA, industrial floors, food industry

Introduction

Thanks to the growing public awareness of the quality of the environment and gradual application of the instruments of environmental policy, we can observe an ever-growing interest by both industrial firms and the general public in the impacts of production and services on the living environment and in the effort to minimize them. The reaction to the

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actual situation gave rise to the development of various methods and approaches to the assessment of the environmental impacts of production and services, which dates back to the beginning of the 60s of the last century. The goal of these efforts is to select, promote and produce a product or a working process that would be the most favourable from the ecological aspect. Nevertheless, the developed methods required a great amount of information and often rendered variant and incomparable results. To bring into effect complete characteristics of the environmental impacts of behaviour of human society, it was necessary to consolidate the hitherto used methodology and to create a more or less uniform apparatus known at present under the term of Life Cycle Assessment (LCA). This method studies the environmental aspects of production and their possible impacts on the living environment in the course of the whole life of the product, starting from the obtainment of raw materials, through the production, utilization, the disposal and waste management, which is "from cradle to grave"

Material and methods

An ecological product should be able to declare its origin and the energy demand in its production. To compare the energy demand of various products, the method of "Life Cycle Assessment of Products" (LCA) is applied. Using this method, we can define the amount of energy necessary for the production and, at the end of the life cycle, also for recycling the definite product (a car, a kilogram of detergent or for example thermal insulation) and also the amount of emissions released into the environment.

The manufacturing of concrete mixtures should not disturb its neighbourhood; it is therefore of prime importance to locate properly the production plant and to use advanced manufacturing technology which eliminates the negative impacts on the living environment.

Dustless and completely waste-free operation of concrete mixing plants should be environmentally-friendly and also give regard to the working environment of the employees. The recycling equipment cleans the residues of concrete mixtures from the washing of agitator trucks and concrete pumps. Clean material and recycled water are returned back to the production process.

The environmentally-friendly behaviour is given by the possibilities offered by up-to-date technologies and not least by a responsible and systematic approach of the manufacturer. It is of prime importance to select correctly the site of the concrete mixing plant and to apply advanced technology to eliminate the negative impact of the manufacturing process on the living environment, to green the surroundings of the producing plants so that the natural landscape pattern is not harmed. The present-day aesthetically designed production plants thus become an important salient feature of their surroundings; they are built up as waste-free production plants fitted with efficient filtering equipment and they are very environmentally-friendly.

As in every industrial activity, the mining of gravel sand also affects the natural landscape pattern. Many companies strive to minimize these impacts, to seek new positive factors for the mining process and to take advantage of them. In the framework of reclaiming industrial land, newly accessed water is incorporated into the landscape. In the exhausted areas, plantings are made, grown trees are planted, shores are reinforced with newly-planted bushes, and this all relates to the regional bio-corridors in the given region. In many cases, the locality is, after the exploitation, environmentally more valuable than before the beginning of the exploitation.

To dispose of concrete in an ecologically accepted manner, there are specialized firms equipped with special facilities. In most cases, the waste originator finances both the recycling and transportation of unneeded concrete to the site of the recycling line. A specialized firm sorts the concrete (and/or debris) and tries to arrange it for further use. For example, it may be used as a component part of compost, to reinforce forest-roads and cart-roads, or to reinforce building sites for various purposes. It is also possible to reuse the broken concrete to prepare concrete.

After a definite period of time, concrete may lose the properties it had when it was placed. It may crack and "spall" due to external actions and it may be generally harmed by frequent use. In this case, the users have several possibilities. They can either remove the given concrete or they can improve it with a new layer of concrete which will cover the shortcomings of the old one. The disadvantage of this method is its profitability in dependence on the total service life of the structure.

As we have already mentioned, this study is limited mainly to poultry breeding and/or to its application in farms specialized primarily in poultry breeding. This example can be used to demonstrate the service life of concrete. The standard service life of concrete when used in a traditional manner is approximately 30-50 years depending on the quality of material, installation, etc. The poultry's excrement contains acid elements which deteriorate the concrete and thus the standard service life is essentially reduced. Installed concrete thus has to be repaired at regular intervals (reconstructed) or it has to be replaced. There exist many technical solutions to prevent or to reduce these problems. It is primarily a case of regular coatings and preventive repairing of local deterioration.

The term recycling in its general meaning means that the existing ripped-up (or milled-out) asphalt can be melted and placed back to the original place or to a new place. The material to be recycled is processed mechanically and thermally. Asphalts are recycled directly on site.

Dry-shakes essentially mean further treatment of concrete, so we can say that recycling is in this aspect practically identical to the recycling of concrete. It is thus a case of overlaying (reconstruction) of the existing concrete layer, where the old surface is used as a base for the placing of a new top layer. Another possibility is to remove the existing concrete, and in this case the recycling would consist of an expert firm crushing the material to obtain the required fraction, sizing it and using it as reinforcement, or it will be added to the new concrete by the dry-shake treatment.

Concrete dry-shakes, as a surface treatment of concrete, are very advantageous; however, they are at the same time essentially more expensive than traditional concrete. Nevertheless, the concrete with dry-shake technology improves its structure and its properties in general. It also considerably extends its service life. This is the reason why at present a lot of firms select exactly the concrete variant with dry-shake technology. The acquisition costs are considerably higher, nevertheless, thanks to a longer service life and higher resistance of the floor, the costs related to the acquisition will return in the form of a longer use of the floor and in the form of lower costs related to its possible repairs.

The aim will therefore be to compare which of the three industrial floors has the best properties, and especially which of them has the least environmental impact.

ADVANTAGES AND DRAWBACKS OF THE COMPARED INDUSTRIAL FLOORS

Table 1

	Concrete	Dry-shakes	Asphalt
Advantages	price	long service life	wear resistance
	strength	resistance to abrasion	noise damping
	stiffness	dustless	watertight
	smooth surfacing		resistant to heat-frost alternation
Drawbacks	dusting	technological exigency	deformation
	low resistance to abrasion	price	follow-up reconstruction with asphalt
	absorptiveness		thermal instability

Results and discussion

The data presented on the individual flows in the evaluated systems were obtained from the records of the companies, technological descriptions and/or verbal consultations with appointed workers of the technological department, and from the records kept by the company environmentalist.

INPUT/OUTPUT MATRIX FOR THE PRODUCTION OF CONCRETE AND DRY-SHAKES

Table 2

Technological operations	**INPUTS**			**OUTPUTS**		
Unit [per 1000 m^2 of products]	**Petrol [litres]**	**Diesel oil [litres]**	**Electric power [kWh]**	**Emissions of CO_2 [g]**	**Noise [dB]**	**Waste [kg]**
Collection of soil	-	32	-	2321	107	-
Soil haulage	-	194.25	-	14089	85	4000 [1)]
Aggregate haulage	-	166.5	-	12076	85	-
Aggregate cartage	-	13	-	943	107	-
Aggregate compaction	-	5	-	363	63	-
Mixing of concrete	-	-	131.35	-	-	76
Concrete cartage	-	177.6	-	12881	85	120
Placing concrete	-	-	87.5	-	73	150
Vibration of concrete	-	-	1.5	-	30	2
Application of dry-shakes						
Pulverisation of emulsions	5	-	-	340		-
Scouring	60	-	-	4075		2
Cutting of expansion joints	24.2	-	-	1643	108	-
Disposal	-	52	-	-	110	375000[2)]

INPUT/OUTPUT MATRIX FOR THE PRODUCTION OF ASPHALT Table 3

Technological operations	**INPUTS**			**OUTPUTS**		
Unit [per 1000 m^2 of products]	**Ground gas [litres]**	**Diesel oil [litres]**	**Electric power [kWh]**	**Emissions [g]**	**Noise [dB]**	**Waste [kg]**
Collection of soil	-	32	-	2321	107	-
Soil haulage	-	194.25	-	14089	85	4000 [1)]
Aggregate haulage	-	166.5	-	12076	85	-
Aggregate cartage	-	13	-	943	107	-
Aggregate compaction	-	5	-	363	63	-
Mixing of asphalt	1250	-	126	69375		
Haulage of asphalt	-	83.25	-	6038	85	-
Placing of asphalt	-	44	-	3191	86	
Rolling of asphalt	-	16	-	1160	74	
Disposal	-	58	-	4207	102	250000[2)]

Notes:

1) in this case the soil was considered as waste in view of the fact that it was not further employed in the production of concrete floor, nevertheless, it can be used as back-fill or fill in further building activities and/or it may be deposited in a dumping place
2) material produced in the disposal of an old asphalt floor may be regarded as waste and deposited in a dumping site, nevertheless, in practice, this "waste" is considered to be valuable raw material for consequent utilization in placing asphalt surfaces

Evaluation of assessed technologies

"*Evaluation of energy demand*", i.e. the consumption of energy obtained by transformation of primary non-renewable resources. Data on the electric power consumption in the individual stages of both assessed technological processes necessary to produce 1 m^2 of products are presented in the following table.

EVALUATION OF ENERGY DEMAND Table 4

Operation	**Unit**	**Concrete, Dry-shakes**	**Asphalt**
Mixing	[kWh/m^2]	0.131	0.126
Placing	[kWh/m^2]	0.088	-
Vibration (compaction)	[kWh/m^2]	0.002	-
TOTAL	**[kWh/m^2]**	**0.221**	**0.126**

The first classification part also includes the consumption of primary energetic raw materials. Table No. 5 represents the amount of gasoline, diesel oil and natural gas necessary to assure all technological processes of the assessed technologies related to the production of 1 m^2 of products.

CONSUMPTION OF PRIMARY ENERGETIC RAW MATERIALS TO ASSURE THE TECHNOLOGICAL PROCESSES Table 5

Raw materials	**Unit**	**Concrete**	**Dry-shakes**	**Asphalt**
Gasoline	[l/m^2]	0.084	0.089	-
Crude oil	[l/m^2]	0.640	0.640	0.612
Natural-gas	[l/m^2]	-	-	1.250
TOTAL	**[l/m^2]**	**0.724**	**0.729**	**1.862**

GENERAL REVIEW OF PRODUCTION OUTPUTS Table 6

PRODUCTION OUTPUTS	Concrete	Dry-shakes	Asphalt
CO_2 [g/m^2]	48.391	48.731	113.763
Waste [kg/m^2]	379.350	379.350	254
Mean noise value [dB] *	93.43	93.43	86.59

*Mean noise level was defined as a weighted mean in which the weights constituted mean operating time of the individual machines

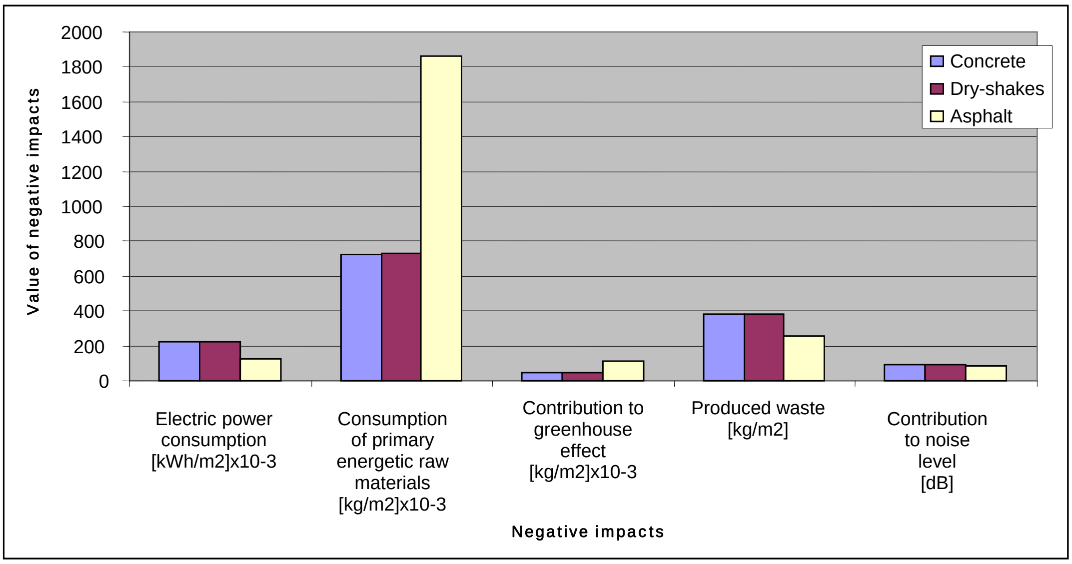
The contribution to the greenhouse effect forms part of the third classified group. From the perspective of its consequences, the greenhouse effect has a global character and it ranks therefore among the most important environmental impacts. It contributes to the increase in global temperature without respect to the site of origin of the emissions.

The amount of waste produced has been included into the fourth classified group, because the amount of waste plays an important role in the ecological and subsequently also in the economic aspects of production.

The measure of noise was included in the last classified group. It was defined as the weighted mean from the aspect of the operating time of the individual working machines. The noise level has a disastrous influence on the standard of living of the population and the workers.

TOTAL NEGATIVE IMPACTS AFFECTING THE LIVING ENVIRONMENT Table 7

Classification group	Units	Concrete	Dry-shakes	Asphalt
Power consumption in examined processes	[kWh/m^2]	0.221	0.221	0.126
Consumption of primary energy raw materials	[kg/m^2]	0.724	0.729	1.862
Contribution to greenhouse effect	[kg/m^2]	48.391×10^{-3}	48.731×10^{-3}	113.763×10^{-3}
Produced waste	[kg/m^2]	379.350	379.350	254.000
Contribution to noise level	[dB]	93.43	93.43	86.59
Total negative impact	**-**	**473.773**	**473.778**	**342.692**



Graph 1. *Total negative impacts on the living environment in the production of surfaces*

The assessed technologies, variants marked as X_1, X_2 and X_3, may be evaluated based on the determined negative environmental impacts, according to the criteria marked A_1 through A5, applying mathematical operational analysis. For this purpose, one of the methods of multi-criterion evaluation was selected. Specifically, in the question is the weighted sum method, the essential part of which is the determination of the weights of the selected criteria. To determine the weights, the so-called scoring method was selected. For each criterion, all the interested persons determined a point scoring evaluation using a 0 to 5 scale. The more important is the criterion for the given person, the higher the score. The review of point scoring by the individual persons is represented in Table 8.

REVIEW OF POINT SCORING OF THE CRITERIA

Table 8

Designation of criterion*	**Person 1**	**Person 2**	**Person 3**
A_1	2	3	3
A_2	5	4	5
A_3	4	3	4
A_4	3	3	2
A_5	1	1	2
Total:	**15**	**14**	**16**

Explanatory notes:

A_1 represents the electric power consumption;

A_2 represents the consumption of primary energetic raw materials, i.e. crude oil and ground gas;

A_3 designates the contribution to the greenhouse effect;

A_4 designates the contribution of the produced waste;

A_5 designates the contribution to the noise level.

On the basis of the above data, the weights of the criteria were determined according to the individual participating persons. The described calculation is represented in Table 9.

CALCULATION OF WEIGHTS FOR THE DEFINED CRITERIA Table 9

Criterion (v_{ij})	**Person 1**	**Person 2**	**Person 3**	**$\sum v_{ij}$**	**Total weight (v_i)**
A_1	0.133	0.214	0.188	0.535	**0.178**
A_2	0.333	0.286	0.313	0.932	**0.311**
A_3	0.267	0.214	0.250	0.731	**0.244**
A_4	0.200	0.214	0.125	0.539	**0.180**
A_5	0.067	0.071	0.125	0.263	**0.088**

The established vector of weights for the needs of this study is therefore as follows:
V = (0.208; 0.291; 0.185; 0.213; 0.102).

Each VHV task is characterized by the so-called criteria matrix, in which the columns correspond to the criteria, in this case A_1 through A_6, and the lines correspond to the evaluated variants (X_1 and X_2). The elements of matrix a_{ij} express the evaluation of i-variant according to j-criterion. The criteria matrix has the following form:

$$Y = \begin{pmatrix} A_1 & A_2 & A_3 & A_4 & A_5 & \\ 0.221 & 0.724 & 48.391\times10^{-3} & 379.350 & 93.43 & X_1 \\ 0.221 & 0.729 & 48.731\times10^{-3} & 379.350 & 93.43 & X_2 \\ 0.126 & 1.862 & 113.763\times10^{-3} & 254.0 & 86.59 & X_3 \end{pmatrix}$$

It is also necessary to determine the ideal and basal variants. The ideal variant is the hypothetic or real variant that attains the best possible values in all the criteria. The ideal variant in the set task is vector H = (0.221; 1.862; 113.763×10^{-3}; 379.350; 93.43). In an analogous manner, a basal variant is the variant that has all the values of the criteria at the lowest level. Also in an analogous manner, the basal variant is vector D = (0.126; 0.724; 48.391×10^{-3}; 254.0; 86.59).

The next step was the unification of the set criteria. Nevertheless, all the criteria of this study are considered to be minimizing criteria and the above-mentioned step was therefore omitted.

The values of the criteria matrix are expressed in various units and it is therefore necessary to normalize all these values according to the relation $r_{ij} = (y'_{ij} - D_j)/(H_j - D_j)$, where D_j represents the lowest value of the j-criterion and H represents the highest value of j-criterion.

The resulting matrix is the so-called normalized matrix in the following form:

$$Y^* = \begin{pmatrix} 1 & 0 & 0 & 1 & 1 \\ 1 & 4.39\times10^{-3} & 5.2\times10^{-3} & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 \end{pmatrix}$$

In the weighted sum method, the optimum variant is the variant that minimizes the sum of the products of weights and the respective criteria values in the event that all the set criteria are minimizing criteria. The resulting evaluation of variants is summed up in Table No.10.

APPLICATION OF THE WEIGHTED SUM METHOD Table 10

Variant	Sum of products of values of criteria matrix a_{ij} and the corresponding weights of the criteria (v_i)	Total	**Order of variants**
X_1	$1 \times 0.178 + 0 + 0 + 1 \times 0.180 + 1\times 0.088$	0.446	**1.**
X_2	$1 \times 0.178 + 4.39\times10^{-3} \times 0.311 + 5.2\times10^{-3} \times 0.244 + 1 \times 0.180 + 1 \times 0.088$	0.448	**2.**
X_3	$0 + 1 \times 0.311 + 1 \times 0.244 + 0 + 0$	0.555	**3.**

Conclusion

The aim of this study was to show the possibilities for application of the life-cycle methodology using a concrete example from the technological practice for the purpose of ecological production and reduction of its environmental impact. This goal has been essentially attained. It has been proven that the LCA methodology may be used for the comparison of environmental impacts of three technological processes. The solution of the study was, however, complicated by several facts, namely the non-existence of analogous materials in available literature and the unavailability of some data from the partnership firm that are subject to trade secrets. A great obstacle we faced was also the fact that it was difficult to obtain concrete information from the manufacturers of construction machinery and mechanization. The precondition for reaching the primary goal was the attainment of secondary goals. Among them, the most difficult goal was the attainment of necessary data and their subsequent conversion to the set functional unit, and in certain cases it was necessary to make use of expert assessment by specialist workers.

At present, a unified methodological procedure to regulate the assessment of the impacts has not yet been defined. The relevant part of the considerations was therefore based on the subjective approach of the compiler, who discussed it with experts in the defined fields both at theoretical and practical levels.

The assessment was based on the electric power consumption and the consumption of primary energetic raw materials (crude oil and ground gas), the contribution to the greenhouse effect, the production of waste and the contribution to the noise level. From the aspect of the total negative environmental impact, only a negligible difference between the technology of concrete floor production and the production of dry-shake floors has been ascertained by means of mutual comparison. A major negative environmental impact of the technology of asphalt floor production against the technology of concrete floor and dry-shake floor production is due to a higher consumption of primary energetic raw materials, in particular of natural gas. The total consumption of primary energetic raw materials is in the case of asphalt floor technology approx. 155% higher than in the technology of concrete and dry-shake floors technology. This consumption is due to the technological parameters of the production of asphalts. Due to this increased energy demand, in particular in the case of the consumption of natural gas, this technology renders a higher contribution to the greenhouse effect, namely by approximately 133% against the consumption of concrete and dry-shake technologies. The positive feature of the production technology of asphalt floors is lower consumption of electric power and lower production of waste compared to the technology of concrete and dry-shake floor production. Electric power consumption is, in the case of asphalt floors, approximately 57 % lower compared to concrete and dry-shake floors; from the aspect of waste production, the asphalt technology is approximately 33 % more economical compared to the remaining technologies. From the aspect of their contribution to the noise level, there are only minimum differences between the assessed technologies; only the contribution of the asphalt technology to the noise level is approximately 7.8% less. From the aspect of the total environmental impact, only minimum difference has been found between concrete and dry-shake technology. The difference between the two technologies and the technology of asphalt production is approximately 27.7% in favour of the asphalt technology.

To attain higher objectivity in the obtained results, the assessed technologies were evaluated using mathematical operations analysis. To this effect, one of the methods of multi-criterion evaluation of variants was applied, namely the weighted sum method. The results proved that the optimum variant is the technology of concrete floor production. The second optimum variant is the technology of dry-shake floor production, and the third one the technology of the asphalt floors. It has to be also emphasized that the differences between the evaluated production technologies were of minimum extent.

Consequently, operations producing the greatest negative impact on the environment were identified. These are in the first place the transportation of raw materials by trucks, waste produced by the disposal of the floor at the end of its life cycle, and also the consumption of electric power, in particular by auxiliary construction mechanization.

Nevertheless, the decision-making process in which mainly investors participate is comprised also of other necessary aspects, particularly the economic information related to the investment and operating costs and/or the market size, and also to the possible social impacts and safety precautions. A very important criterion to be taken into consideration in the decision-making process is the total service life of the product, in this case of the floors in agricultural premises. The expected service life of concrete floors is approximately 30 years. The dry-shake treatment of concrete floors increases the cost of realization of the floor (by approx. 60 – 100 Czech Crowns/m^2); nevertheless, it highly improves the technical properties of the resulting product, primarily its resistance to external influences, its durability and its load-bearing capacity. Thanks to this treatment the dry-shake floor can attain much longer service life than standard concrete floors. The expected service life of asphalt floors is approximately 25 years.

The expected application of the results obtained by the solutions from this study offers to the management of the respective firm further improvement of the ecological - economic characteristics of the technology of floor production in agricultural premises. At the same time, the results of the study also offer a primary instruction for the application of LCA methodology to the technologies of production of various types of industrial floors.

References:

[1] ČSN EN ISO 14040 Environmetal Management – Life cycle assessment – Principles and framework. CNI 1998, [Environmentální management – Posuzování životního cyklu – Zásady a osnova]. Praha: Český normalizační institut, 1998.

[2] *Environmetal Management – Life cycle assessment – Life cycle impact assessment CNI 2001.* [ČSN EN ISO 14042 Environmentální management – Posuzování životního cyklu – Hodnocení dopadů životního cyklu]. Praha: Český normalizační institut, 2001.

[3] *The governmental policy of the environment*. Praha: MŽP ČR, 1999.

[4] BODNÁROVÁ L. *The composite material in the building industry*. Brno: VUT, FAST, 2002

[5] BUREŠ J., MALOTA D., KULÍSEK K. *Heat engineering.* Brno: VUT, 1990.

[6] DROCHYTKA, R. *Atmhospheric corrosion in the concrete*. Prague: IKAS, 1998.

[7] KAYALI O, HAQUE M.N., ZHU B. *Some characteristics of high strength fiber reinforced lightweight aggregate concrete*. NY, First Edition.

[8] KOTOVICOVÁ, J. a kol. *The biodegradable waste*. Brno: Mendelova zemědělská a lesnická univerzita v Brně, 2008, 109 p. ISBN 978-80-7375-229-3

[9] MALÝ, K. Life cycle of floors for the food industry and agriculture. Environmental Management - Proceedings of the International Conference. Žilina: Strix et VeV. First Edition, 2008.

[10] NOVÁK, M. *Review of the resource pollution*. Prague, 2000.

[11] NEDBAL, F. *Special concrete*. Prague: SVB, 2001.

[12] RUSKO, M., KURACINA, R., KOTOVICOVA, J., KREČMEROVÁ, T. *Chaps of the safety and environmental management.* Žilina: Strix et VeV, Edícia EV-20, 2007. ISBN 978-80-89281-17-6. 2007

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