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# Innovative systemic approach for promoting sustainable innovation for zero construction waste

Zero  
construction  
waste

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## Abstract

**Purpose** – The purpose of this paper is to focus on optimization of recycling of concrete from lightweight aggregates containing expanded glass and hard polyurethane (PU) and on the issue of importance of environmental management in constructions, to produce the new combination using rest, construction waste of concrete from lightweight aggregates and hard PU new raw components of concrete from lightweight aggregates, as key reactive materials.

**Design/methodology/approach** – The research for this paper is based on the collection and analysis of quantitative and qualitative data, non-linear programming (NLP) model and experimental research.

**Findings** – Results from the new recycled material have been compared with the normal existing concrete from lightweight aggregates. Characteristics of recycled lightweight concrete (LWC) such as density, compressive strength and thermal conductivity have been investigated and have been compared with normal existing concrete from lightweight aggregates. Results indicate that it is possible to recycle LWC aggregates and hard PU waste.

**Research limitations/implications** – Research was limited to management of construction.

**Practical implications** – The use of waste LWC with aggregates containing expanded glass and hard PU seems to be necessary for the production of cheaper and environment-friendly LWC.

**Originality/value** – The method shows great possibilities for increasing use of construction waste materials from LWC containing expanded glass and hard PU in order to benefit from the better use of existing construction waste. Characteristics such as density, compressive strength and thermal conductivity from the new recycled material have been compared with normal existing concrete from lightweight aggregates. They change depending on the type and part of waste as well as the type and part of fresh binding components. Thus, a new recycled material is created with new values of density, compressive strength and thermal conductivity, which conform to the compressive strength class and rules on heat protection and efficient use of energy in buildings (SI OJ RS No. 42/2002). Laboratory density, compressive strength and thermal conductivity tests results showed that LWC can be produced by the use of waste LWC with aggregates containing expanded glass and hard PU. The author proposes a model of recycling isolating materials, made of hard PU and LWC with aggregates containing expanded glass, based on recycling and NLP.

**Keywords** Concretes, Compressive strength, Density, Recycling, Thermal conductivity, Cybernetics

**Paper type** Research paper

## 1. Introduction

Sustainable development is becoming an increasingly important issue of business policy. Companies do not compete only for the best quality, the widest variety and best price but more and more frequently for environmental protection in terms of sustainable development and corporate social responsibility. The environmental management system on the basis of a company's own initiative and creative cooperation within the business system and its surroundings, is far more important than restrictions of the state forcing companies into environmental management. Companies prove their respect



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towards the capacity of interior sources and the surroundings of the business system not only from the viewpoint of economy and quantity but first of all from the viewpoint of sustainability. It is possible for various companies (also construction companies) irrespective of geographic, social, human, technical, cultural conditions, among others to include a system for prevention of environmental pollution in line with socioeconomic and other needs in their business policy. Construction, one of the oldest activities of mankind, has an important effect on the socioeconomic development and at the same time sets an indelible seal on the surroundings and the environment. It influences the economical dynamics of society and also has an important effect on the environment and surroundings. The activities connected with constructions have long-term effects on the change in the appearance of a region, as well as on natural resources and waste management. The current environmental policy is based upon the concept of sustainable development. The latter has been gaining increasing importance both in the international community and the Member States of the European Union (EU) as a form of development bringing prosperity to future generations. Innovation is of vital importance not only for those who want to increase or sustain economic growth in a given area (region, state and the like), but also for those who benefit(in)directly. According to this, producing as much as possible is no more a central issue that should affect or change the economic course of development or improve quality of life. Since the majority of natural resources are not unlimited and renewable, we can ensure equal opportunities to future generations only provided that we employ responsibility in the field of resources management. In its sustainable development strategy, the EU has set the severing of links between economic growth, use of natural resources and production of waste (Hart, 2007) as one of its primary goals. The model of recycling the construction waste of concrete from lightweight aggregates is developed to incorporate environmental performance in the design of building operations and minimize construction waste.

## 2. Experiments

### 2.1 Lab experiment

The model of recycling construction waste of concrete from lightweight aggregates containing expanded glass was developed in order to include environmental performance in the design of building operations and minimizing construction waste. The quantities of waste lightweight concrete (LWC) made of expanded glass currently are not so large, because of this fact the question of whether it is possible and economical to collect such waste separately arises. However, from an environmental point of view, the recycling or reuse of a building is generally better than demolition, because the environmental costs of energy, water and materials for refurbishment and reuse are less. In recent years, life cycle assessment (LCA) has frequently been used to evaluate the environmental issues associated with solid waste management (Hunt, 1995; Björklund *et al.*, 2000; Finnveden *et al.*, 2000; Grant *et al.*, 2003). The main advantage of using LCA on solid waste management systems is that the approach covers all impacts associated with the waste management in a systematic way, including all processes in the solid waste system as well as upstream and downstream of the waste management system (Kirkeby *et al.*, 2006). Several models for environmental assessment of treatment and disposal of municipal solid waste have been presented in the last decade. The IWM-model (White *et al.*, 1995; McDougall *et al.*, 2001) applies life cycle thinking on handling of municipal solid waste and includes first a spreadsheet and later a more advanced model for calculating life cycle inventories. In our

research, we started with LCA. LCA is a standardized tool, which has the purpose of minimizing potential impact on the environment, human health and on resources. The boundaries are thus more narrowly defined because economics are not included (Hansen and Gilberg, 2003 in Kirkeby *et al.*, 2006). The objective of this part of the research is to determine if crushed LWC from lightweight aggregates containing expanded glass can be used as an aggregate in concrete (recycled LWC aggregates). The characteristics of density, compressive strength and thermal conductivity from the new recycled material were compared with the normal existing concrete from lightweight aggregates.

Creative collaboration and new waste management philosophy have led to a new perspective: rest (or remnant), and waste (construction) material is a raw (construction) material. Table I presents contrasts between “old” and “new” rest and waste approach based on dialectical systems theory (DST) (Kralj, 2008).

A variety of raw materials are used to produce concrete from lightweight aggregates. One of them is LWC with aggregates containing expanded glass. The raw material for LWC with aggregates containing expanded glass or – to be more precise – recycled glass, of which millions of tons are collected in the Federal Republic of Germany every year employing – to all intents and purposes – a perfect recycling system. LWC with aggregates containing expanded glass makes use of only the valuable raw material which for technical reasons, cannot be utilized by the glass industry to manufacture new glass products, e.g. fine glass shards. LWC with aggregates containing expanded glass thus makes a decisive contribution to perfecting the glass recycling process, whilst at the same time, protecting natural resources. Apart from its areas of use in the classic and additional building materials industry, LWC with aggregates containing expanded glass is also gaining popularity in special applications. Figure 1 shows LWC waste of LWC from aggregates containing expanded glass.

WAS	IS (DST)
Rest and waste material Disposal 	Rest and waste = raw material New product 

**Table I.**  
Contrasts between “old”  
and “new” rest and waste  
approach



**Figure 1.**  
LWC waste of LWC from  
aggregates containing  
expanded glass

In the first place, it was important to see how the recycled LWC aggregate is produced, because this will determine the properties of the material. Because of the relatively small amounts, and the fact that it was part of a construction which also contains other materials, it is likely that the recycled LWC aggregate will be produced in an ordinary recycling plant. Because of its lower density as normal concrete it would be treated as such ([www.sintef.no/EuroLightCon](http://www.sintef.no/EuroLightCon), July 18, 2008). LWC waste was obtained as a waste from the IGM Stavbar recasting plant, demolition debris from construction site, and laboratory samples. The main material used in this study was LWC with aggregates containing expanded glass. Mixed samples were crushed to small pieces, granular size (mm) of crumbled waste concrete from LWC with aggregates containing expanded glass as shown in Figure 2. Figure 2 shows crushed LWC waste from LWC with aggregates containing expanded glass as a new recycling possibility.

The figure of production of LWC with aggregates containing expanded glass is available on the internet ([www.poraver.de](http://www.poraver.de), December 14, 2008). The chemical and physical properties of the LWC with aggregates containing expanded glass used in the study were summarized and the data are available on the internet ([www.poraver.de](http://www.poraver.de), December 14, 2008). For recycling, we needed crushed construction waste of concrete from lightweight aggregates Poraver<sup>®</sup> and a new fresh LWC as a bind. For this purpose, we took fresh concrete from lightweight aggregates Poraver<sup>®</sup>. We used LCA. LCA is a technique for assessing the environmental aspects and potential impacts associated with the product (ISO 14031:1999(E), 1999) and can assist in identifying opportunities to improve the environmental aspects of products at various points in their life cycle (ISO 14040:1997(E), 1997). The accent was made on identifying opportunities for improving the environmental aspects of LWC and the next step as a recycling crushed construction waste from concrete from lightweight aggregates and fresh concrete from lightweight aggregates as a binding. Recycling followed as the next activity under normal room conditions:

- assembling rest construction waste from LWC with aggregates containing expanded glass and hard polyurethane (PU);
- crumbling into small pieces (Figure 3), after that we took crumbled construction waste of concrete from LWC with aggregates containing expanded glass and



**Figure 2.**  
Crushed LWC waste from  
LWC with aggregates  
containing expanded glass



**Figure 3.**  
“New” recycled material,  
LWC from aggregates  
containing expanded glass  
and hard PU

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hard PU (mechanical reprocessing), as a raw input material in the processing line to the standard mould;

- charging volume of standard mould used for preparation of concrete specimens for compression test with “new” raw material;
- binding reaction occurred between new raw materials of fresh LWC with aggregates containing expanded glass and rest (waste) material of LWC with aggregates containing expanded glass and hard PU;
- binding process or the binding reaction refer to hydration of cement; and
- quality control.

Characteristics of density, compressive strength and thermal conductivity from the newly recycled material were compared with normal existing concrete from lightweight aggregates.

### *2.2 Non-linear programming model*

The hybrid process parameters were optimized using a non-linear programming (NLP) model. Optimization could increase annual profit.

The parameters in the composite model were simultaneously optimized using the GAMS/MINOS software. This NLP can be solved using a large-scale reduced gradient method (e.g. MINOS). This model is non-convex, it does not guarantee a global optimization solution, but it quickly provides good results for non-trivial, complex processes. This NLP model uses the simple linear equations and polynomial of the third order. The parameter  $X_{com}$  can denote the value of composite mass. The pure concrete composition is presented as a 0 percent composite mass ( $X_{com} = 0$ ). The parameter  $X_{com}$  can vary between 0 and 0.2; it can be presented by the composition of a composite. As the composite can be old concrete and PU, we presented a different analysis in Chapter 2.

The objective function (*OB*) of the NLP model is to search for the best composition of composite. The best composition presents the highest hardness (*H*) and the lowest density (*D*) and heat conductivity (*Ct*):

$$OB = 100H - 100D - 100Ct \tag{1}$$

**280** *2.2.1 Composite from old concrete and PU.* The different compositions and properties (*H*, *D* and *Ct*) are shown in Figure 4.

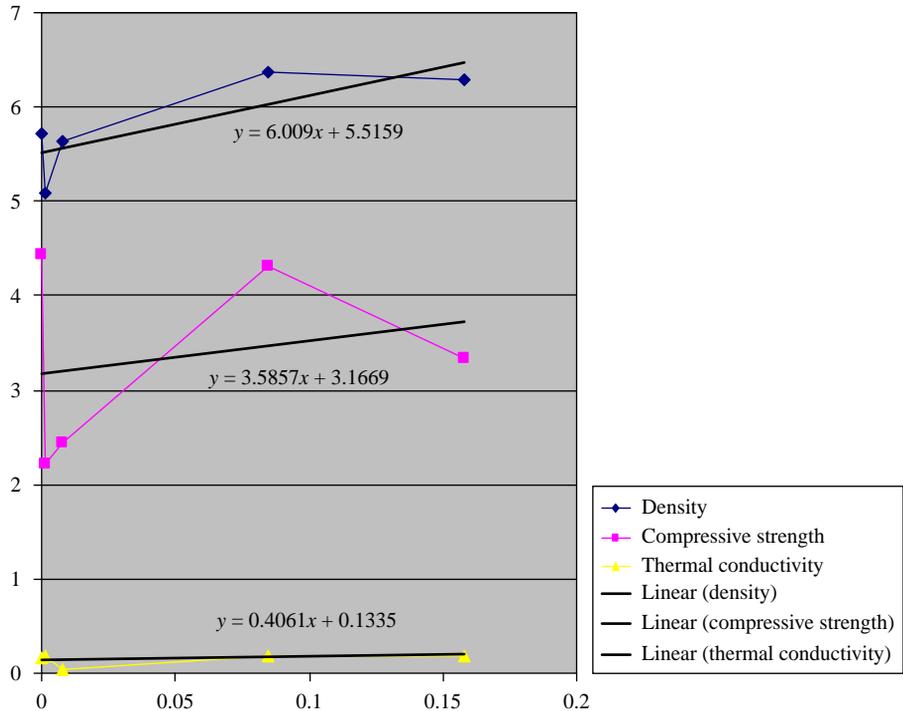
There properties can be characterized by the linear or non-linear model.  
Non-linear model – polynomial of the third order:

$$D = -359.3X_{com}^{**3} + 10.3X_{com}^{**2} + 12.66X_{com} + 5.44 \tag{2}$$

$$H = -17,693X_{com}^{**3} + 4,163.7X_{com}^{**2} - 218.13X_{com} + 3.63 \tag{3}$$

$$Ct = -1,536.6X_{com}^{**3} + 373.24X_{com}^{**2} - 20.59X_{com} + 0.187 \tag{4}$$

Where the composition of a composite ( $X_{com}$ ) was presented old concrete and PU. In non-linear model, the best composition of composite is  $X_{com} = 0.011$ ; the best composition was composed from 0.011 part of old concrete and PU, and 0.989 part of new concrete.



**Figure 4.**  
The different compositions and properties (*H*, *D* and *Ct*)

Linear model:

$$D = 6.009 X_{com} + 5.5159 \quad (5)$$

$$H = 3.5857 X_{com} + 3.1669 \quad (6)$$

$$Ct = 0.401 X_{com} + 0.1335 \quad (7)$$

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Where the composition of a composite ( $X_{com}$ ) was presented old concrete and PU. In the linear model, the best composition of composite was  $X_{com} = 0.2$  – limitation; the best composition was composed of 0.2 part of old concrete and PU, and 0.8 part of new concrete.

2.2.2 *Old concrete.* The different compositions and properties ( $H$ ,  $D$  and  $Ct$ ) are shown in Figure 5. Here only the linear model was presented.

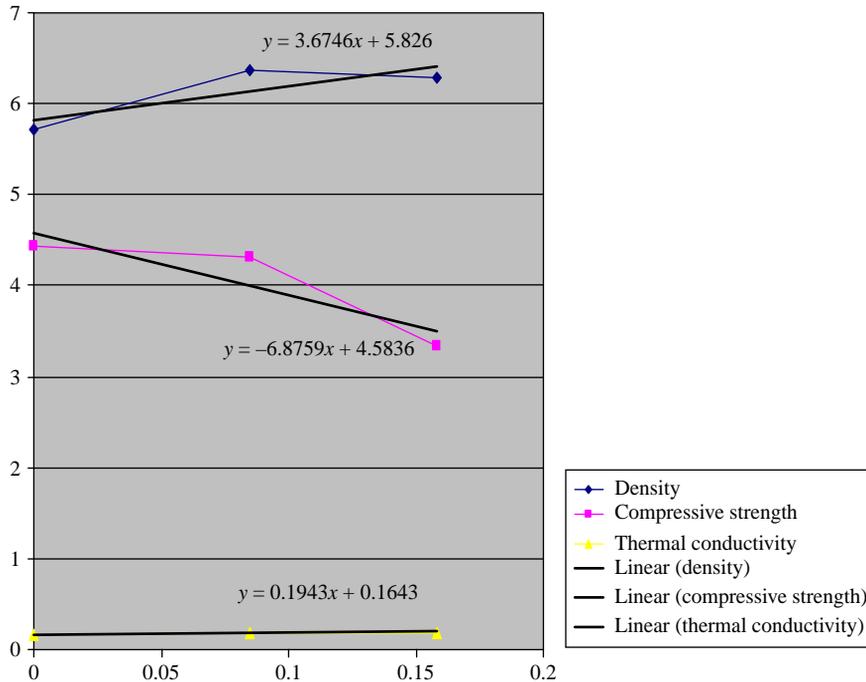
Linear model:

$$D = 3.6746 X_{com} + 5.826 \quad (8)$$

$$H = -6.8759 X_{com} + 4.5836 \quad (9)$$

$$Ct = 0.1943 X_{com} + 0.1643 \quad (10)$$

Where the composition of a composite ( $X_{com}$ ) was presented old concrete. In the linear model, the best composition of composite is  $X_{com} = 0.2$  – limitation; the best composition was composed of 0.2 part of old concrete, and 0.8 part of new concrete.



**Figure 5.**  
The different  
compositions and  
properties ( $H$ ,  $D$  and  $Ct$ )

2.2.3 Old PU. The different compositions and properties ( $H$ ,  $D$  and  $Ct$ ) are shown in Figure 6. Here only linear model was presented.

Linear model:

$$D = -366.47 X_{com} + 5.719 \quad (11)$$

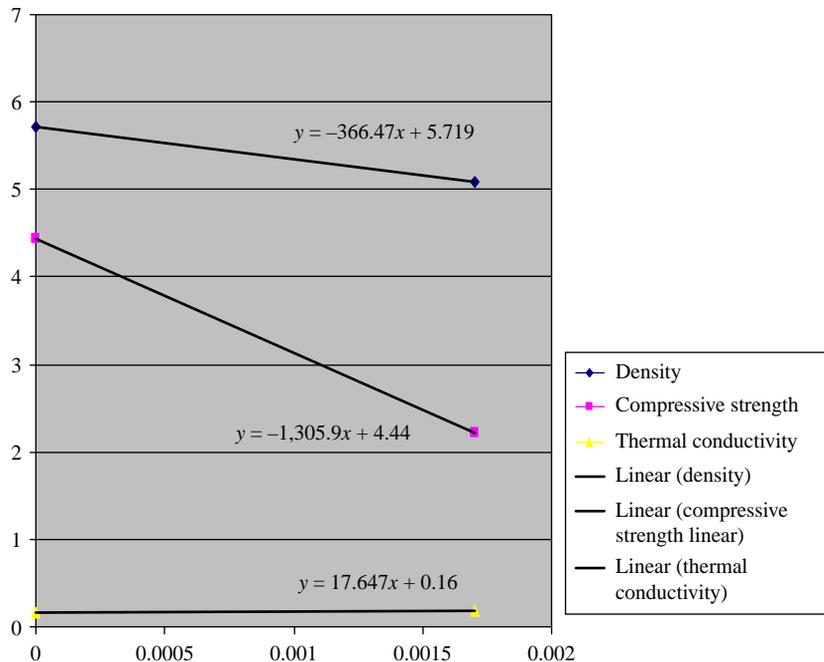
$$H = -1,305.9 X_{com} + 4.44 \quad (12)$$

$$Ct = 17.647 X_{com} + 0.16 \quad (13)$$

Where the composition of a composite ( $X_{com}$ ) was presented PU. In the linear model, the best composition of composite was  $X_{com} = 0.002$  – limitation; the best composition was composed of 0.002 part of PU, and 0.998 part of new concrete.

### 3. Results and discussion

This chapter focuses on a practical example of successfully integrating waste management principles and reusing with the reuse and recycling of construction waste of concrete from LWC with aggregates containing expanded glass and hard PU. New economic issues dictate the redefining of economic interests in the wake of the recognition, that the natural environment is a limited production factor and not, as had previously been considered, the only supplier of raw materials (Kralj *et al.*, 2005c). The objective of this study was to investigate waste management and recycling of construction waste of concrete from lightweight aggregates (density from about  $600 \text{ kg m}^{-3}$ ) and hard PU (density from about  $40\text{-}60 \text{ kg m}^{-3}$ ). A commercially available concrete from lightweight aggregates Poraver<sup>®</sup> and hard PU were selected for this investigation. The volume of the standard mould used



**Figure 6.**  
The different compositions and properties ( $H$ ,  $D$  and  $Ct$ )

for preparation of concrete specimens for compression test, dimensions  $150 \times 150 \times 150$  mm, was charged with rest, construction waste material of concrete from lightweight aggregates Poraver<sup>®</sup> and hard PU, the rest of the volume with new raw materials of concrete from lightweight aggregates Poraver<sup>®</sup> or hard PU was used as binding. It was added to the mould separately and not during the mixing of concrete, because we first investigated the capability of fresh LCW as a binding and the ratio between waste and fresh LCW with aggregates containing expanded glass. The mould was first charged with waste material and then filled with fresh concrete. Another possibility for this is during the mixing of concrete. In this case, waste LCW will assume the role of LWA. A prescription of raw materials of concrete from lightweight aggregates Poraver<sup>®</sup> was used, as supplied producer. Characteristics such as density, compressive strength and thermal conductivity of produced material samples in the scope of the research are given in Table II.

Recycled material has higher density, compressive strength and thermal conductivity similar to the standard one. Characteristics of density, compressive strength and thermal conductivity are changing depending on the types and parts of waste, as well as the types and parts of fresh binding components. Data concerning the 28-days-cube-compressive strength values of the materials are given in Table II. The 28-days-cube-compressive strength values of the concrete samples were changed according to the material mixing ratios. Owing to low ratio of the LWC waste in the material composition finally caused maximum compressive strength values at the end of 28 days was maximum. The compressive strength values of LWC samples were under  $4.36 \text{ N mm}^{-2}$ . By reason of the low-compressive strength, the LWC with LWC waste additive can be recommended for use as a coating and dividing material in constructions, because of its insulating features.

Test cube	Mass of waste	Mass of LWC (kg)	Density ( $\text{kg/m}^3$ )	Compressive strength ( $\text{N/mm}^2$ )	Thermal conductivity ( $\text{W/mK}$ )
1 <sup>a</sup>	–	1.93	571.9	4.44	0.18
2 <sup>a</sup>	–	1.95	577.8	4.67	0.18
3 <sup>a</sup>	–	1.99	589.6	4.36	0.18
	<i>LWC (kg)</i>	<i>Recycled</i>			
4 <sup>b</sup>	0.2	2.15	637.0	4.31	0.19
5 <sup>b</sup>	0.2	2.14	634.1	4.22	0.19
6 <sup>b</sup>	0.2	2.18	645.9	4.04	0.19
7 <sup>c</sup>	0.4	2.12	628.2	3.33	0.21
8 <sup>c</sup>	0.4	2.12	628.2	3.64	0.21
9 <sup>c</sup>	0.4	2.13	631.1	3.82	0.21
	<i>Hard PU (<math>\text{kg}^{-1}</math>)</i>				
10	0.003	1.72	509.6	2.22	0.21
11	0.003	1.69	500.7	2.00	0.21
12	0.003	1.68	497.8	2.31	0.21
	<i>Hard PU and LWC (kg)</i>				
10	0.015	1.90	563.0	2.44	0.2
11	0.015	1.96	580.7	2.67	0.2
12	0.015	1.91	564.9	2.227	0.2

**Notes:** <sup>a</sup>Standard LWC; <sup>b</sup>recycled LWC (0.2 kg); <sup>c</sup>recycled LWC (0.4 kg)

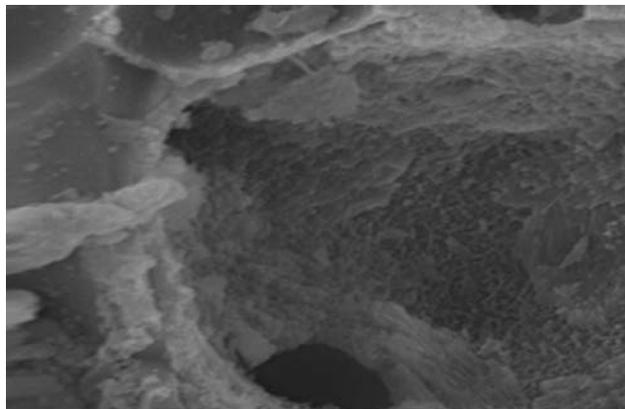
**Table II.**  
Characteristics of recycled material, and concrete from lightweight aggregates Poraver<sup>®</sup>

The thermal conductivity of produced material samples was observed. Thermal conductivities of samples No. 3, 4 and 5 were  $0.19 \text{ W m}^{-1} \text{ K}$  and of samples 7 and 8 and were determined as  $0.21 \text{ W m}^{-1} \text{ K}$ . Evaluating the thermal conductivities of produced material samples together with their compressive strengths and density, shows into suitable for use as a recycled LWC produced from waste LWC with aggregates containing expanded glass and hard PU in building as a coating and dividing material for features to be insulated. Thus, a new recycled material LWC material with aggregates containing expanded glass and hard PU was created with new characteristics of density, compressive strength and thermal conductivity, which conforms with the compressive strength class and rules on heat protection and energy efficiency use of energy in buildings (OJ RS No. 42/2002). Figure 7 shows the new recycled product. It can be used for heat protection and efficient use of energy in buildings.

Figures 8 and 9 show LWC with aggregates containing expanded glass scanning electron microscope. Figure 8 shows structure of recycled LWC with aggregates containing expanded glass with an air void, characteristic of LWC with aggregates



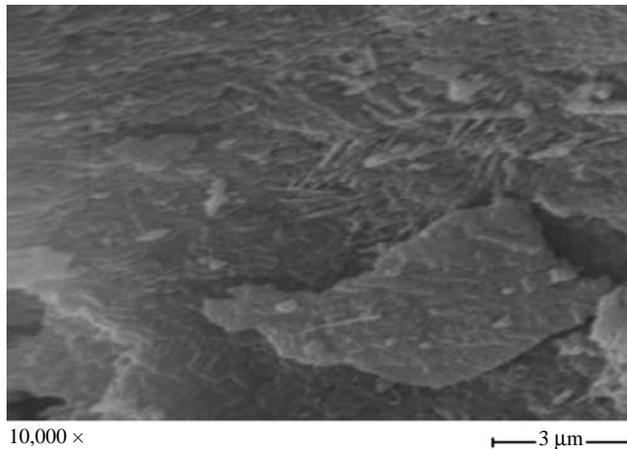
**Figure 7.**  
Recycled “new” material  
from LWC with  
aggregates containing  
expanded glass



**Figure 8.**  
LWC with aggregates  
containing expanded glass  
scanning electron  
microscope

5,000 ×

7 μm



**Figure 9.**  
Recycled material from  
LWC with aggregates  
containing expanded glass  
scanning electron  
microscope

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containing expanded glass. Figure 9 shows a piece of waste LWC with aggregates containing expanded glass incorporated in a recycled “new” LWC product.

This paper presents a user friendly model for LWC (with aggregates containing expanded glass) and hard PU recycling and minimizing resource consumption and potential impacts for waste management systems. A new waste management philosophy is leading to a new perspective: rest and waste (construction) material is a raw (construction) material. The model can be used to recycle another construction waste such as insulation material.

#### 4. Conclusions

This research presents an experimental study into recycling LWC with aggregates containing expanded glass and hard PU. Promoting such causes and activities as recycling should redound to business’s benefit (Reinhardt, 2007). Construction wastes of concrete from lightweight aggregates provide us an opportunity to think about this. The whole process of creative problem solving is a complex system in itself, dynamically changing overtime, with permanently interacting system elements, it requires a systems thinking perspective in order to be understood and applied (Mulej, 1992). On this basis, we thought about recycling of construction waste from concrete from lightweight aggregates and hard PU.

In our research, we proposed a model of recycling construction materials, made from LWC, with aggregates containing expanded glass and hard PU. It can be seen from the results that recycling of concrete from lightweight aggregates Poraver<sup>®</sup> and hard PU improves the life cycle of the material, and there is no more remaining of waste concrete from LWC with aggregates containing expanded glass and hard PU. With this solution, the material is brought to the life cycle of a product. To include, it is possible to innovate production processes.

Our results show that concrete waste material of concrete from lightweight aggregates and LWC with aggregates containing expanded glass and hard PU can be incorporated into the recycling process. We showed that specific selection of technological procedure and the quantity of remaining waste concrete from lightweight aggregates and LWC with aggregates containing expanded glass and hard PU, can play

a crucial role for the characteristics of the recycled material. Thus, a new recycled material has been created with new characteristics of density, compressive strength and thermal conductivity, which conforms with the rules on heat protection and efficient use of energy in buildings (SI OJ RS No. 42/2002) and can be used for heat protection and efficient use of energy in buildings. Laboratory density, compressive strength and thermal conductivity tests results showed that LWC can be produced by the use of waste LWC with aggregates containing expanded glass and hard PU. However, the use of waste LWC with aggregates containing expanded glass and hard PU seems to be necessary for the production of cheaper and environment-friendly composite with the density, compressive strength and thermal conductivity similar to control LWC containing with only with aggregates containing expanded glass.

The method shows great possibilities for increasing the use of construction waste materials from LWC with aggregates containing expanded glass and hard PU in order to benefit from better use of the available existing construction waste. The suggested recycling and experimental study is a very effective tool for the solution (with aggregates containing expanded glass) recycling problems. The model is confirmed by patent notification Nr. P-200600191, the conclusion for patent publication being dated November 15, 2006, and was tested during construction practice. It was awarded by World Intellectual Property Organization (WIPO) in 2008 as shown in Figure 10.

In this study, the possibilities of using waste LWC with aggregates containing expanded glass and hard PU for producing new composite were researched and the following conclusions were obtained.

Since the unit mass of the produced LWC samples varied between 0.05 and  $0.25 \text{ kg dm}^{-3}$ , it is in the class of heat-insulating LWC in respect of those unit mass values:

- Owing to the low ratio of the LWC waste in the material composition causing maximum compressive strength values finally at the end of 28 days. The compressive strength values of LWC samples were under  $4.36 \text{ N mm}^{-2}$ .
- It was shown that the 28-days-cube-compressive strength values were lower for the whole of the LWC samples. Therefore, it is possible to say that LWCs including waste LWC with aggregates containing expanded glass as a coating material in buildings is useful, because of its insulating features. Comparing the thermal conductivity values of the produced LWC samples with materials such as brick ( $0.45\text{-}0.60 \text{ W mK}^{-1}$ ), briquette ( $0.70\text{-}1.0 \text{ W mK}^{-1}$ ), pumice concrete ( $0.29 \text{ W mK}^{-1}$ ) and Ytong ( $0.23 \text{ W mK}^{-1}$ ), which have a widespread usage area in buildings, it can be seen that the LWCs samples including LWC waste have lower values ( $0.194\text{-}0.220 \text{ W mK}^{-1}$ ) compared to other masonry materials (Öztürk and Bayraklı, 2005).
- The used material in this research was waste from the production end of Stavbar IGM. According to other building materials, it could be supplied cheaply. As to the observations, tests, experiments and evaluations on LWC material samples, it was concluded that the LWC with waste LWC, and with aggregates containing expanded glass can be used as a coating material in during construction.

The challenge of addressing climate change in the context of moving society towards the environmental, economic and social goals of sustainability requires radical innovation of cleaner technologies and processes which meet individual and social needs at acceptable costs with significantly reduced environmental impacts (Foxon, 2006). This paper has



Figure 10.  
WIPO award for the best  
eco inventor

argued for the application of systems thinking and practice to the promotion of innovation for sustainability. Systems thinking has been used as a framework for understanding innovation processes. Systemic thinking helps better than one-sided thinking, co-operation helps better than isolation, creativity helps better than routinism. Innovative business is supported in innovative societies, USOMID and similar method support effectiveness and efficiency of efforts aimed at excellent quality in order for the suppliers to satisfy their customers (Mulej and Zenko, 2004).

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