HOUSING DEVELOPMENT IN SERBIA IN THE CONTEXT OF GLOBALIZATION AND INTEGRATIONS

VOLUME I | EXPERIENCES AND APPROACHES

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ENVIRONMENTAL PROFILE OF BUILDING MATERIALS COMMONLY USED IN RESIDENTIAL BUILDING IN BELGRADE

Abstract | Environmentally friendly building materials have become an important factor in contemporary design and building concepts as well as a prerequisite for creating sustainable buildings and architecture as a part of global sustainable development. In Serbia, this concept is still at its very beginning. Therefore, it is important to determine what our building practice has offered so far. For scope of this paper, Belgrade residential building stock was chosen as a model whose environmental properties were evaluated using previously developed evaluation methods and tools. The results were used to determine overall environmental performance of residential buildings in Belgrade.

Key words | building materials, environmental profile, environmental impact

ЕКОЛОШКИ ПРОФИЛ ГРАЂЕВИНСКИХ МАТЕРИЈАЛА НАЈЧЕШЋЕ КОРИШЋЕНИХ У СТАМБЕНОЈ АРХИТЕКТУРИ БЕОГРАДА

Апстракт | Еколошка исправност грађевинских материјала постала је значајан фактор у савременом концепту пројектовања и грађења и предуслов за стварање одрживих архитектонских објеката у контексту глобалног одрживог развоја. Обзиром да се у Србији овакав концепт налази у почетној фази, било би од значаја утврдити каква су искуства у досадашњој грађевинској пракси. За потребе овог рада анализиран је постојећи грађевински фонд града Београда, као модел на коме су примењени већ развијени модели и алати за процену еколошке исправности грађевинских материјала. На бази тих анализа дата је укупна процена еколошких карактеристика стамбених објеката на територији Београда.

Кључне речи | грађевински материјали, еколошки профил, еколошки утицај

1. INTRODUCTION

In time of global efforts towards continuous amelioration of negative impacts on the environment by rational use of natural resources and energy consumption as well as by alleviating the effects of local industries, there are increasing demands to address those efforts to the building sector in order to investigate its potential role in sustainable development. Almost half of the total world energy movements are oriented to the building sector, while the largest part of their activities concerns the production and processing of raw materials and building materials and products. Besides energy issues, there are other negative environmental effects caused by the construction industry, such as natural resource depletion or copious amounts of diverse waste materials that it leaves behind. A great number of predicted or unpredicted adverse outcomes, some of which could be equaled to a disaster, are to a great extent effectuated both by technological processes and building construction systems and techniques. Therefore, the choice and application of building materials should be seen as a very delicate and responsible process that can provoke many negative consequences on direct users as well as the environment. By knowing and managing the environmental profile for each particular building material used in construction, it is possible to improve overall building environmental performance. Based on previous research results |1|, this paper goes on to deal with building materials regarding their environmental properties, trying to define their environmental profile. By analyzing building materials used in typical examples of the residential building stock in Belgrade, this paper attempts at recognizing relevant ecological performance of building materials, determining their environmental profile and registering their potential environmental effects. The main goal of this research was to collect data about environmental profiles of building materials and products applied in Serbian common building practice so far. Such data may be helpful in indicating its capacity and position within the developed system of environmentally conscious construction in the EU as a part of overall sustainable development tendencies.

2. THE THEORETICAL CONTEXT OF THE RESEARCH

Basic principles of sustainable development are tight fitted into a controlled and synchronous development of a society. Based on the rational and responsible use of natural resources in order to fulfill actual needs besides preserving environmental capacities for future generations, sustainable development can be perceived as the only possible solution for the progressive decline of humankind. It has been almost twenty years since the UN conference on the environment was held in Rio de Janeiro in 1992, with the *Agenda 21* as its action plan. The plan promoted specific directives to be applied both on global and local levels regarding adoption and use of sustainable development strategies. Nevertheless, many questions remain open, such as the capacity and sustainability of natural resources, protection of bio diversity, acceleration of climate changes, reduction of the total energy consumption, minimization of waste and negative environmental impacts of chemical and biological contamination, transfer to new technologies and alternative energy sources, possibilities to realize the ecological city concept, etc. However, concerns about natural resource depletion, increasing energy needs or progressive waste generation seem to be crucial for further survival and development of humankind. Having in mind that architectural and civil engineering activities are leaders in total worldwide energy consumption, and that most of this energy is targeted at resource exploitation and processing of building materials, the need arose for more serious examination of building activities than in former building practice. Analyzing energy efficiency and environment friendly properties of buildings, especially regarding the building materials used, must be considered as very important in long-term sustainable development.

There are numerous currently running projects supported by the United Nations, the European Union and governments of certain countries that deal with sustainable development, environment friendly buildings and the assessment of the effects that building industry and constructions have on the natural and built environment. Special attention is paid to building materials regarding possibilities and effects of choice as well as the final impact that materials bear on the environment. Therefore, by knowing the environmental profile of a particular material, the whole building profile assessment can be completed with respect to its efficiency and environmental impact. Thus, in the context of the local market, a preliminary review of environmental performance of the existing building stock can be differentiated and future trends of building construction can be proposed.

3. DEFINING THE RELEVANT MODEL SAMPLE

Construction of residential buildings has been a prevalent building activity in Belgrade region; the period before and after World War II was followed with mass renovation and construction lasting until the late 1980s, which was resumed in the last ten years under the changed market conditions. Before World War II, small detached family homes were the prevalent type of constructed buildings. A recent Belgrade building stock survey conducted in 2011 |9|, showed that more than 10% of buildings date from 1919 to 1945. On the other hand, during post war renovation, 52% of buildings were constructed in the period 1946–1970. After the golden period of mass renovation and reconstruction, building activities in Belgrade entered stagnation leading to moderate progress. Starting from the 1970s until 2000, only 30% of buildings were constructed (approximately 10% per decade). In the last ten years the downward trend continued, leading to only 7% of buildings constructed in Belgrade. According to the same survey, 67% of the whole building stock is comprised of single family detached houses. Apart from these, 16% are labeled as family houses (up to four family units in a single building) and 17% as multifamily houses.

Knowing that more than three quarters of the Serbian building stock comprises one floor buildings, it is obvious that the single family detached house can be found as the most prevalent type of building in Serbia as well as in Belgrade. The majority of buildings that were constructed in Belgrade until the 1960s were built as masonry buildings, with few glazed surfaces and pitched roofs. This kind of building structure involved thick, heavy masonry walls (massive wall bearing system) that were made on site. Using prefabricated and semi-prefabricated systems and elements was very rare in constructing such buildings. Façade walls were commonly made of brick (71%), clay masonry block (18%) and concrete panels (8%). The average wall thickness varied between 25 and 30 cm, which was determined by the brick size applied (distinction between old and new brick format).

Starting from the 1960s, the increasing need for dwellings in Belgrade was solved by erecting massive multifamily houses that were constructed using various prefabricated building systems and techniques. As an illustration, this was the time when New Belgrade was established, where more than 50 residential housing estates were constructed until 1985, using different industrial prefabricated construction systems. The buildings from that period were built using reinforced concrete in the form of off–site prefabricated elements mounted on site. This resulted in large apartment block estates as well as in a variety of high-rise buildings. Concrete was the prevailing material used in planning and construction and it can be found in bearing structures (foundations, columns, beams, slabs, etc.) but also in other finish and decorative components (partition walls, façade wall cladding, tiles, etc.).

Between 1990 and 2000, the socio-political and economical changes in the region resulted in diminished intensity of construction and stagnation of all activities concerning the building sector. The change of circumstances on the market after the year 2000 led to the changes in building site organization. This was the time of the construction of individual residential buildings that varied in their urban context and type of financing. Therefore, mass prefabricated systems that had been dominant were abandoned and replaced by an improved combined traditional construction system. Based on a particular site context, the building structure is made as a concrete skeleton frame but also as a massive clay block bearing wall strengthened with an additional concrete frame. Intermediate floors are made as full concrete slabs but also as combined slabs using semi-prefabricated clay elements and concrete ("TM" and "LMT" slabs). Façade walls are commonly made of clay blocks, additionally strengthened with a concrete frame. Regarding the roof system, statistical data show that there is the majority, or 87% of pitched roofs in Belgrade, while the rest are flat roofs from the years after World War II. Pitched roofs are mainly covered with clay tiles (72%), followed by Salonit tiles containing cement and asbestos fiber (11%). In most houses, the attic space is not used. Window frames on residential buildings are commonly made of wood (85%) or PVC (13%), while aluminium is very rare (3%). A quarter of windows are 30-40 years old and are obsolescent.

Based on the above statistical data, three different typical residential buildings were chosen for the research model, representing typical examples of the mentioned periods regarding the applied construction principles and systems as well as building materials and products that were used (Figure 1). The buildings were chosen in order to define specific models for the environmental assessment of building materials. In order to make data cross comparison easier, the chosen models were labeled A-C. The buildings that were chosen as referent models for this research are:

1. Building A – a three-floor single family detached residential building, built in a residential street with similar houses in Voždovac. Realized as a masonry type building in 1960, it represents the family house built in the post war period (1946-1970). It was built with the basement level and the attic space that are not used for common activities. The building structure was made with massive masonry walls with the thickness of 38cm on the ground floor and 25 cm on the first floor. The ceiling structure was made with semi-prefabricated system elements known as "Avramenko", which was in common use in that period. The building is covered with four-side pitched roof on a wooden structure. The roof surface is covered with clay tiles. The windows are wooden, double framed (wide space) with single glass. All windows are equipped with external plastic blinds.
2. Building B – eight-floor multifamily row house–central, residential building from New Belgrade, Block 64, 29 Gandijeva Street. It was built in the late 1980s as a part of one of the last multifamily city blocks realized in the prefabricated construction system. The bearing structure was made of large concrete panels with the thickness of 16 cm, with additional layers depending on the specific position on the building. All concrete elements were made off site and finally assembled on site during construction. The partition walls were made as light-weight gypsum walls with wooden substructure, except for the sanitary and kitchen walls that were realized as a thin concrete battery including installation pipes and drainages. The intermediate floors were made as full 22 cm concrete slabs, covered with a few additional layers depending on position (sound insulation, cement, ceramic tiles, hydro insulation, wooden parquet, etc.). The façade walls were made as large concrete panels containing three layers of concrete with the intermediate thermal insulation layer (5 cm EPS). The building has a basic

type flat roof covered with concrete tiles. The windows are wooden, double framed (connected) with double separate glass. All windows are equipped with external plastic blinds.

3. Building C – six-floor + attic multifamily free standing residential building in an urban city block in the old part of Belgrade, 1 Janka Veselinovića Street. It was realized in the contemporary improved building system in 2007. The building structure was made as a combination of a concrete skeleton frame with a massive concrete and clay block bearing wall, strengthened with the additional concrete frame. The intermediate floors were made as full 20 cm concrete slabs. The roof construction was made in curved combined 20 cm slab using semi-prefabricated clay elements and concrete ("LMT" type slab). The floors were covered with a few additional layers depending on the position (sound insulation, cement, ceramic tiles, hydro insulation, wooden parquet, etc.). The partition walls were made of brick, hollow clay and concrete blocks with the thickness of 6.5-20 cm, depending on the position. The façade walls were made as a ventilated cavity wall, including internal clay blocks, with additional layers of thermal insulation and façade brick layer on the external side. Parts of façade walls were covered with cement mortar and painted. The windows are aluminium and wood-aluminium with single frame, glazed with thermal insulating glazing units 4+12+4 mm. All windows are equipped with external aluminium blinds.

Figure 1 |Chosen building types (from left to right) A,B,C |5|

Representative for the typical periods of construction, the model buildings show significant differences regarding the applied design process, structural characteristics, materials and products as well as the building technology and site organization (Table 1). Therefore, by adequate comparison and evaluation of relevant characteristics of the applied building materials and products, it is realistic to expect data that could facilitate the initial evaluation of the environmental profile of typical buildings in Serbian building practice.

Table 1 | Basic characteristics of model buildings

	building A	building B	building C
Location	Rastka Petrovića Street, Voždovac, Belgrade	Gandijeva Street Block 64, New Belgrade	Janka Veselinovića Street, Vračar, Belgrade
type of building	residential-single family	residential-multifamily	residential-multifamily
date of erection	1960	late 1980s	2007
plot organization	detached house	row of buildings-central	detached house
floor area	60m^2	360m^2	265m^2
height of building	basement+ground floor+1	basement+ground floor+6	basement+ground floor+4+attic
building technology	traditional	industrialized, prefabricated	improved traditional
structural system	masonry bearing brick walls	prefabricated, large panel, reinforced concrete system	monolith- *in situ*, skeleton, reinforced concrete system
partitions	built *in situ*	prefabricated	built *in situ*

4. METHODS FOR RECOGNITION AND EVALUATION OF ENVIRONMENTAL PROPERTIES

Understanding the complexity of the problem of recognition and evaluation of environmental properties of building materials requires specific attention to different aspects from which this problem could be analyzed. Namely, it is necessary to take into account the status and resource capacities of an environment, different environmental effects of building materials, energy consumption, life cycle assessment of materials and buildings, etc. It is also necessary to recognize and classify possible impacts which could cause the environmental properties of materials to be exhibited in their interaction with the environment. The terms *environmental properties* and *environmental profile of building materials* concern different impacts that occur in interaction between built environment–building and material–user–surroundings and which directly or indirectly influence the quality of the environment by changing it. The types of impacts that could be classified concern: the state and exhaustion of resources, pollution of the eco-system, health impact on users, energy consumption in different phases of the life cycle of the material, generation and management of waste materials, potentials for recycling and re-use of materials, and re-starting a new life cycle. The term *life-cycle* |6| of a material or a product becomes a crucial point of interest and considers observation of all successive and connected phases in its life, from the extraction of the raw material, through the production and application to its final deposition. This introduces complexity into possible evaluation and classification of building materials with respect to their ecological or environmental properties. At this moment, one of the transitional solutions for this problem is found in curtailing several different measures and methods for recognition, testing and evaluation of an environmental profile of a building material. Therefore, it is necessary first to define the criteria that will help future evaluation of materials. This step will be followed by further systematization and ranking of results depending on the intensity and significance of the expected impact.

In the present-day world practice there are several systems and tools designed for recognition of ecological/environmental characteristics of building materials and evaluation of their impact on the built and natural environment. Although many of them were developed for the needs of local economies, almost all are based on the method of Life Cycle Assessment (LCA) which is additionally adjusted to the local possibilities of evaluation of the preferred indicators. In view of the above mentioned international experiences, it was thought that by analyzing the individual methods already used in practice some of their principles were possible to apply to the evaluation in this particular research. Therefore, the following evaluation tools were analyzed: Environmental Preference Method – EPM, Hazardous Building Materials – HBM, a guide to the selection of environmentally responsible alternatives, and the European Union directives and recommendations for the design choice of environment friendly products.

4.1. The Environmental Preference Method – EPM |3|

The EPM was developed in the Netherlands in 1991. It was adjusted to the needs of local economy, offering possibility for practical and simple choice of environment friendly building materials and products that were commonly used in construction of residential buildings. The approach to the problem of recognition and evaluation of environmental impacts is based on the method of life cycle assessment but as simplified estimation done upon accessible and previously obtained data. Unlike the LCA method, the EPM is not focused on the quantitative analysis of certain products expressed in units such as kg or m3, but it makes a wider comparative analysis of optional elements – functional units applicable for certain positions in a building. The principle of this method is to take different factors into account simultaneously, such as various damages to the eco system, consumption/exhaustion of resources, energy consumption (in all phases of production, including transport), environmental pollution with different waste and hazardous materials, waste disposal problems, hazardous emissions into the atmosphere, global warming, impact on human beings, re-use and recycling possibilities, etc. The result of this method is a list of preferable materials and products, each of which has been evaluated according to its environmental impacts and adjusted to its typical positions within a building. This method also factors in whether it is the case of construction or refurbishment of a building. Material preference for a certain position is made through a four level ranking system which classifies materials and products into three priority levels (I, II, III preference), or excludes them from the final choice. Since this method includes all relevant aspects, it could be considered as a specific combination of global and problem analysis, which easily adapts to the needs of practical implementation. The final product of the EPM method is a manual that contains a list of preferable materials and products, sorted according to their position in different components of the building. It has already been used as a tool for environmental evaluation in some European projects|10|.

4.2. Hazardous Building Materials – HBM |8|

This guide was created as a result of a wider project which dealt with impacts that building materials have on users and the wider environment|2|. The intention of its authors was to create a manual that would serve as an auxiliary tool in the process of material choice, in a way that the chosen materials should have the least impact on users' health, and have minimal negative impact on the environment; at the same time, they should fulfill other criteria, such as technical, esthetical and financial. Based on experienced knowledge and available information (like in the case of the EPM method), without any additional analyses and tests, the evaluation of building materials and products that are typical of construction of residential buildings is conducted. The factors taken into account are as follows:

- global factors – global warming, acid rains, damages to the ozone layer, resource exhaustion, bio-diversity;
- local factors – soil contamination, generation and management of waste materials, water and air quality, bio-diversity, resource exhaustion, noise, impact of radon;
- health factors – sick building syndrome, air quality, water quality, impact of fibrous materials, impact of radon, electro-magnetic radiation, impact of volatile materials.

Like with the EPM method, a list of preferable materials and products is created, specified according to their typical position in the building and offering a choice of ecologically friendly materials. Alternative materials and products are ranked considering their technical, health, economic and environmental criteria. The focus of the analysis is shifted to the field of health impact and risk to users and this could be understood both as uniqueness and a special contribution of this method. The HBM method shows certain similarities with the EPM method regarding sources and choice of data according to which the evaluation of ecological properties is conducted (previous knowledge and available information), while in the process of creation of the criteria and indicators for evaluation it relies on the method of life cycle assessment.

4.3. The European Union – directives and recommendations |4|

In the EU countries, great efforts are made towards finding methods and procedures for environmental evaluation of building materials |11|. Numerous working groups and committees work to create criteria and indicators for the evaluation of ecological impact on the environment, with the final goal to form a system of recommendations for designing environmentally acceptable buildings. Many of these recommendations are already included in the EU directives, and set as obligatory for all participants in the building sector activities. Also, plenty of these remarks and directives have already been incorporated in various software tools developed for the evaluation of the total impact of a building on the environment |12|. Some of these recommendations concern:

- reduction of the need for building materials (design rationalization);
- maximization of use of environmentally friendly and healthy materials;
- use of durable materials;
- use of materials from renewable resources;
- maximization of dismantling possibilities of buildings and its components;
- maximization of re-use of buildings and its components;
- designing with the idea of possible recycling;
- application of recycled materials;
- avoiding application of hazardous substances (PVC, solvents);
- obligation to create a data base of expected effects.

Whether they are based on basic analysis of each particular material or pointed towards the overall assessment of the whole building (as a part of a certain rating system), all of these are based on the principles of the 3R concept |7|, recently introduced into the EU building market. Started in 2004 as an action plan introduced by the G8, the 3R concept was proposed to improve the efficiency of resources and products operation in order to minimize possible negative impacts on the environment. The 3Rs refer to Reduce, Reuse and Recycle as three possible options of resource management, targeted to overall diminishing of negative environmental impact both locally and globally. Along energy issues, the 3R concept targets waste as one of the most serious problems of the contemporary society. Waste generation and waste management are connected to a full scope of activities of local economies and can be seen as an unavoidable part of human development. Constant growth and developing of humankind as well as intensive urbanization have led to progressive production of a variety of waste matter and its disposal in the environment. Introduced as a concept tool based on the principles of sustainable development , the 3R can be defined as a complex waste management platform that deals with questions such as depleted resources, possible reduction in projected activities, the environmental impact during various processes, introducing reused and recycled materials and components in everyday life, etc. All the efforts are aimed to reduce the total amount of produced waste in order to mitigate potential negative impacts on the environment. In building industry, the 3R concept is concerned with huge amounts of waste that result from different activities during the processes of construction and deconstruction. Recent data show that the amount of construction and demolition waste (C&D waste) in the EU reaches 35% of total waste generated. The amount of produced C&D waste in Germany was at the level of 200 millions of tonnes in 2008, which is over 50% of all waste produced in the country. The total amount of produced C&D waste in Serbia is at a much lower level, which can be explained by socio-political and economic conditions in the region. The National Statistical Office introduced data that showed almost 1 million of tonnes of C&D waste generated in Serbia in 2009.

Applying the 3Rs in architecture and construction involves all three principles (reduce, reuse and recycle) by targeting activities from resource management, processing and use of building materials and products, to the whole building management. With basic aims of reducing the production and use of goods, the 3R position in architecture and construction stands for overall reduction in generated and used energy and resources throughout the lifecycle of a building, the reuse of resources, materials and components as parts of generated C&D waste, increasing use of recyclable and recycled materials in building construction, and also for activating and reconditioning of the existing buildings for other uses. In short term, the 3Rs can be defined as a complex platform based on different possibilities and directions for managing global targets. Each direction can be defined through a variety of criteria that call for activities such as:

- technical, technological, and economical optimization of the building structure;
- using the advantages of modularity in planning and design;
- promoting use of local resources and materials;
- increasing use of prefabricated elements;
- improving internal comfort by accurately designed building envelope;
- increasing possibilities for building deconstruction through appropriate design of connections between elements and building materials;
- using materials from renewable resources;
- using environment friendly materials with no or low negative impact on the environment during manufacturing processes;
- using materials that need reasonable amounts of energy to produce;
- using friendly materials with no negative impact on the environment or the users during occupancy of the building;
- using long lasting materials in order to enable their reuse;

- increasing usage of partly and fully recyclable materials by using materials with short time of decomposition in the landfill.

It is obvious that the process of recognition of impacts and evaluation of environmental properties is ambiguous. Therefore, it would be very difficult at this moment to set universal approaches and evaluation tools which would yield satisfactory results for all environments according to the mentioned levels. Nevertheless, with digesting certain methods and procedures as well as modifying and extending them according to the local needs, it could be possible to achieve a satisfactory level of environmental evaluation of building materials and products with a possibility to transfer the acquired results to the level of a building as the desired final product.

5. DATA INVENTORY, ANALYSIS AND EVALUATION

Due to the relevance of the mentioned aspects, the proposed data systematization and possibilities for practical and simple use (which is of special significance for this particular research), the EPM method could be considered as an adequate starting point for the evaluation of the chosen research models. Another reason for choosing this method is the fact that in evaluation and ranking process, it covers almost all of the defined criteria which are relevant for the evaluation of the environmental impact. Therefore, the EPM method will be used as the primary evaluation method of the created model data base. In order to clarify and define possible negative effects and direct impacts on the users' health, further testing will be conducted by using the HBM method which specifically takes into consideration health aspects. Finally, after the data have been analyzed by these two methods, they will be additionally examined with respect to the relevant EU criteria, directives and recommendations introduced through the 3R concept.

The need for making a comparable and compatible data base which would offer a starting point for further evaluation of the environmental profile of building materials brought about the creation of the data base on the model buildings of this research. The obtained data formed a data base containing relevant information about all materials and products that were applied on the chosen model buildings. For better understanding and comparison of the results, the applied materials and products were sorted regarding their position, i.e. the component created within a building, such as foundations, structural elements and systems, external and internal partitions, coverings, equipment elements, etc. Sorted in this way, the data were later evaluated according to the following principle (Table 2).

The first step data analysis was conducted using the EPM evaluation method, as a primary method for determining the ecological profile of materials. Ranking of materials was conducted with the use of a four-step scale: 1-4. Values 1-3 concern the materials whose use is considered acceptable, ranking from the most (value 1) to the least preferred (value 3), while value 4 (not recommended) is assigned to those materials which have or create certain negative environmental impact, or to those which have an acceptable alternative that could be used at a particular position in the building. Whenever it was possible in this work, the preferred material was noted as a possible alternative and better ecological solution for the particular position in the building.

The second step analysis was conducted using the HBM evaluation method, but focused on determining the negative impact that building materials could have on the health of the users. Materials were evaluated and ranked in two possible situations: during their exploitation and during dismantling from the position they were built in, when certain negative environmental impacts could occur. The results are expressed as E/D, where value E relates to possible impact during exploitation while value D shows impact that material has during its dismantling or demolition. Ranking is shown as a scale 0-3, where values 0-2 represent those materials that are acceptable for application in a certain position (value 0 – most acceptable, value 2 – least acceptable), while value 3 is assigned to the materials which are not recommended, or which could be replaced with other, more acceptable alternatives. As with the EPM method alternative materials were recommended in this analysis as well, whenever it was possible.

The final data analysis was conducted using some parameters defined by the 3R concept and the directives set by the EU regulations. All three levels (directions) of the concept were included in the analysis by checking material preference regarding the possible Reduce, Reuse and Recycle factor. It was found that only a preliminary check list of some of the 3R parameters would be satisfactory, without conducting a complex analysis of the model buildings that could exceed the scope of this paper. The basic 3R analysis check list was set only by registering potential attachment of building materials to some of the predefined 3R values (Reduce, Reuse, Recycle). Thus the particular analyzed material could be labeled with one to three possible Rs. The first R label requiring a possible reduction of activities was explored by checking the use of modularity in the model buildings as well as of prefabricated elements and components. That principle was found favorable regarding overall reductions in the engaged energy and on site activities as well as the time and personnel needed. The second possible R label was checked against the possibilities for reusing building materials and building components, either separately or entirely. To be marked as potential for re-use, a particular material/component should enable subsequent use without a generous change of its structure. The last R label was given to those materials which can be easily recycled, with small amount of energy required and with a minor impact on the environment during the recycling process.

Table 2 | Evaluation of environmental characteristics of applied building materials and products used in the model buildings A, B and C with EPM, HBM and 3R methods

BUILDING A				**BUILDING B**				**BUILDING C**			
applied material	evaluation method			applied material	evaluation method			applied material	evaluation method		
	EPM	HBM	3R		EPM	HBM	3R		EPM	HBM	3R
	recomm. alternat.	E/D			recomm. alternat.	E/D			recomm. alternat.	E/D	
position in building - FOUNDATIONS											
stone	1	0/0	-/R/R	reinforc. concrete	4, NOT recomm. concrete with reclaim. aggreg.	0/0	-/-/R	reinforc. concrete	4, NOT recomm. concrete with reclaim. aggreg.	0/0	-/-/R
position in building – FLOOR ON THE GROUND											
				reinforc. concrete	4, NOT recomm. concrete with reclaim. aggreg.	0/0	-/-/R	reinforc. concrete	4, NOT recomm. concrete with reclaim. aggreg.	0/0	-/-/R
plain concrete	4, NOT recomm. concret	0/0	-/-/R	plain concrete	4, NOT recomm. concrete	0/0	-/-/R	lean concrete	4, NOT recomm. concrete	0/0	-/-/R

	e with reclaim. aggreg.				with reclaim. aggreg.				with reclaim. aggreg.		
				sand	2	0/0	-/R/-				
gravel	4, NOT recomm. reclaim. aggreg.	0/0	-/R/R	gravel	4, NOT recomm. reclaim. aggreg.	0/0	-/R/R				
bitumin. damp membra.	1	0/0	-/-/-	bitumin. damp membra.	1	0/0	-/-/-				
asphalt	1	0/0	-/-/-	asphalt	1	0/0	-/-/-				
				cement screed	3	0/0	-/-/R	reinforc. cement screed	-	0/0	-/-/R
				concrete tiles	4, NOT recomm. concrete with reclaim. aggreg.	0/0	R/R/R				
EPS insulation	2	0/0	R/R*/R								
Plastic laminate	3	0/0	R/R/R**								
parquet	1	0/0	R/R/R								
position in building – EXTERNAL WALLS BELOW GROUND											
stone	1	0/0	-/R/R	reinforc. concrete	4, NOT recomm. hollow concr. blocks	0/0	-/-/R	reinforc. concrete	4, NOT recomm. concrete with reclaim. aggreg.	0/0	-/-/R
cement-lime mortar	2	0/0	-/-/R	bitumino. paint	1	0/0	-/-/-				
				bitumino. paper	1	0/0	-/-/-				
				bitumino. damp membra.	1	0/0	-/-/-				
				clay bricks	2	0/0	R/R*/R				

* Re-using possibilities depends on dissmantling ability of particular material/element, without changing its form, structure, dimensions.

** Potential recycling rate benefit depends on possibilities for recycling entire element/material, or just some part of it`s structure.

BUILDING A				BUILDING B				BUILDING C			
applied material	evaluation method			applied material	evaluation method			applied material	evaluation method		
	EPM	HBM	3R		EPM	HBM	3R		EPM	HBM	3R
	recomm. alternat.	E/D			recomm. alternat.	E/D			recomm. alternat.	E/D	
position in building – EXTERNAL WALLS											
				prefabr. reinforc. concrete	4, NOT recomm. concrete with reclaim. aggreg.	0/0	R/R/R				
				lightweig. concrete	2	0/0	-/-/R	clay blocks	1	0/0	R/R*/R
clay bricks	2	0/0	R/R*/R	clay bricks	2	0/0	R/R*/R	clay bricks	2	0/0	R/-/R
				EPS insulation	2	0/0	R/R/R	EPS insulation	2	0/0	R/R/R
cement-lime mortar	2	0/0	-/-/R	aluminum foil	-	0/0	-/-/R	cement-lime mortar	2	0/0	-/-/R
				acrylic paint	3	0/0	-/-/-				
position in building – INTERNAL WALLS											
				reinforc. concrete	4, NOT recomm.	0/0	-/-/R	reinforc. concrete	4, NOT recomm.	0/0	-/-/R
				lightweig. concrete	2	0/0	-/-/R	clay blocks	1	0/0	R/R*/R
clay bricks	2	0/0	R/R*/R	gypsum boards+ timber frame construc.	1	0/0	-/R/R	clay bricks	2	0/0	R/R*/R
ceramic tiles	1	0/0	R/-/R	ceramic tiles	1	0/0	R/-/R	ceramic tiles	1	0/0	R/-/R
				vinyl coated paper	-	0/0	-/-/-				
cement-lime plaster	2	0/0	-/-/R	thermo insulating plaster	3	0/0	-/-/R	cement-lime plaster	2	0/0	-/-/R
mineral paint	1	0/0	-/-/-	mineral paint	1	0/0	-/-/-	mineral paint	1	0/0	-/-/-
position in building – INTERMEDIATE FLOOR											
prefabr. reinforc. concrete rib	4, NOT recomm. concrete with reclaim. aggreg.	0/0	R/R/R	prefabr. reinforc. concrete slab	4, NOT recomm. concrete with reclaim. aggreg.	0/0	R/R/R	reinforc. concrete slab	4, NOT recomm. concrete with reclaim. aggreg.	0/0	-/-/R
thin-layer	-	-	-/-/-	thin-layer	-	-	-/-/-	thin-layer	-	-	-/-/-

plaster				plaster				plaster			
plain concrete	4, NOT recomm.	0/0	-/-/R	screed	3	0/0	-/-/R	screed	3	0/0	-/-/R
sand	2	0/0	-/R/-	mineral wool	1	0/2	R/R/R	extrud. polystyr.	4, NOT recomm. / EPS	0/0	R/R/R
board	1	0/0	R/R/R	PVC foil	4, NOT recomm.	0/0	-/-/-	PVC foil	4, NOT recomm.	0/0	-/-/-
timber batten	1	0/0	R/R/R	bitumin. damp memb.	1	0/0	-/-/-	bitumin. damp memb.	1	0/0	-/-/-
parquet	1	0/0	R/R/R	stripped oak parquet	2	0/0	R/R/R	parquet	1	0/0	R/R/R
				vinyl-asbestos tiles	4, NOT recommended	1/3	-/-/-	laminate parquet	2	0/0	R/R/R

* Re-using possibilities depends on dissmantling ability of particular material/element, without changing its form, structure, dimensions.

** Potential recycling rate benefit depends on possibilities for recycling entire element/material, or just some part of it`s structure.

BUILDING A				BUILDING B				BUILDING C			
applied material	evaluation method			applied material	evaluation method			applied material	evaluation method		
	EPM	HBM	3R		EPM	HBM	3R		EPM	HBM	3R
	recomm. alternat.	E/D			recomm. alternat.	E/D			recomm. alternat.	E/D	
rammed earth	1	0/0	-/R/R	phenol-form-aldehyde boards	4, NOT recomm. / mineral wool	0/0	-/-/-				
reed	1	0/0	R/R/R	terazzo tiles	1	0/0	R/R/R				
ceramic tiles	2	0/0	R/-/R	ceramic tiles	2	0/0	R/-/R	ceramic tiles	2	0/0	R/-/R
mineral paint	1	0/0	-/-/-	mineral paint	1	0/0	-/-/-	mineral paint	1	0/0	-/-/-
cement - lime plaster	2	0/0	-/-/-	rubber sheet covering	1	0/0	R/R/R				
				wooden strips	1	0/0	R/R/R				
synthetic floor covering	4, NOT recomm. / wood, ceramics	0/0	R/R/-	synthetic floor covering	4, NOT recomm. / wood, ceramics	0/0	R/R/-				
position in building – ROOF STRUCTURE											
pitched roof	1			flat roof	3			pitched roof	1		
				Prefab. reinforc. concrete slab	4, NOT recomm. / lightweig. concrete	0/0	R/R/R	reinforc. concrete	4, NOT recomm. / concrete with reclaim. aggreg.	0/0	-/-/R

				lightweig. concrete	2	0/0	-/-/R	hollow ceramic elememts	2	0/0	R/-/R
								cement - lime plaster	2	0/0	-/-/-
				aluminum vapour barrier	2	0/0	-/-/R	aluminum vapour barrier	2	0/0	-/-/R
wooden substruct.	1	0/0	R/R/R	polyuret. insulation	4, NOT recomm. EPS, mineral wool	0/0	R/R/R	mineral wool	2	0/2 EPS, XPS, porofen	R/R/R
bitumin. damp membra.	2	0/0	-/-/-	bitumin. damp membra.	2	0/0	-/-/-	wooden substruct.	1	0/0	R/R/R
zinc steel sheet	2	0/0	-/-/R	sand	2	0/0	-/R/-				
				gravel	2	0/0	-/R/-				
clay roof tiles	2	0/0	R/R/R	concrete tiles	2	0/0	R/R/R	alumin. sheet	4, NOT recomm. ceramic tiles	0/0	R/R/R
position in building – EXTERNAL DOORS / WINDOWS											
wooden frame	1	0/0	R/R/R	laminated recomm. wooden frame	1	0/0	R/R/R				
PVC frame	4, NOT recomm. wooden frame	0/0	R/R/R	aluminum frame	3	0/0	R/R/R	aluminum frame	3	0/0	R/R/R
single glazing in double frame	3	0/0	R/R/R	single glazing in double frame	3	0/0	R/R/R				

BUILDING A				**BUILDING B**				**BUILDING C**			
applied material	evaluation method			applied material	evaluation method			applied material	evaluation method		
	EPM	HBM	3R		EPM	HBM	3R		EPM	HBM	3R
	recomm. alternat.	E/D			recomm. alternat.	E/D			recomm. alternat.	E/D	
thermo insulating glazing	1	0/0	R/R/R					thermo insulating glazing	1	0/0	R/R/R
window sealant	-	0/0	-/-/-	window sealant	-	0/0	-/-/-	silicone sealant	1	0/0	-/-/-
PVC blinds	4, NOT recommended	0/0	R/R/R	PVC blinds	4, NOT recommended	0/0	R/R/R	aluminum blinds	3	0/0	R/R/R

	wooden blinds				wooden blinds						
zinc-steel sheet window sill	2	0/0	-/-/R	zinc-steel sheet window sill	2	0/0	-/-/R	aluminum sheet window sill	3	0/0	-/-/R
position in building – INTERNAL DOORS / WINDOWS											
wooden frame	1	0/0	R/R/R	wooden frame	1	0/0	R/R/R	MDF	3	0/0	-/R/-
				steel frame	2	0/0	-/R/R	wood veneer	1	0/0	-/-/R
honey-comb with hardbo. skins	1	0/0	-/R/R	honey-comb with hardbo. skins	1	0/0	R/R/R				
position in building – METAL FRAMED WINDOWS, DOORS AND PARTITION WALLS											
				steel frame	2	0/0	-/R/R	anodized aluminum frame	4, NOT recomm. steel frame	0/0	-/R/R
				single glazing	4, NOT recomm. insulating glazing	0/0	R/R/R	insulating glass	1	0/0	R/R/R
				Reinf. glass	2	0/0	R/R/R	Alumin. sheet	3	0/0	R/R/R
				metal paint	-	-					
position in building – RAILINGS...											
steel frame	3	0/0	R/R/R	steel frame	3	0/0	R/R/R	steel frame	3	0/0	R/R/R
				reinforc. concrete	4, NOT recomm. masonry walls	0/0	R/R/R	cement compo-site	3	0/0	R/R/R
metal paint			-/-/-	metal paint			-/-/-	metal paint			-/-/-
acrylic paint	3	0/0	-/-/-	acrylic paint	3	0/0	-/-/-	acrylic paint	3	0/0	-/-/-

6. THE INTERPRETATION OF RESULTS

The review of the results shows significant difference among the evaluation methods used. With the EPM methods, the evaluation results show that a great number of applied materials and products partly or completely fail to fulfill the desired criteria in all model buildings. The results of evaluation using the HBM method show that, with several exceptions, almost all of the applied materials fulfill the required conditions. This indicates the inability to digest the results of these two methods or to interpret them uniformly. It also indicates the need that each of applied methods should be used separately and the obtained results should be compared and combined later in order to achieve the best possible overall assessment of buildings.

The evaluation conducted according to the EPM method showed that in all model buildings, certain materials were evaluated as ecologically unacceptable and due to their environmental impact they were not recommended for use. These materials and reasons for being considered unacceptable for use are shown in Table 3.

Table 3 | Unacceptable building materials used in the model buildings

Unacceptable building material	Negative environmental impact
natural gravel	exhaustion of resources change of landscape due to excavation of raw material energy consumption during excavation of raw material
lean and plain concrete	energy consumption during cement production CO_2 emission
reinforced concrete	pollution during ore extraction and steel production energy consumption during cement production CO_2 emission
prefabricated concrete panels	pollution during ore extraction and steel production energy consumption during cement production CO_2 emission
single glazing	impact on living comfort great energy consumption for heating and cooling
plastic shutters and blinds, vinyl coated papers	content of PVC
PVC foils	environmental impact during production complicated recycling process
vinyl – asbestos plates	content of vinyl and potentially hazardous asbestos fibers toxic impact on users' health during dismantling complicated procedure of deposition of asbestos waste
"porofen" – phenol-formaldehyde boards	content of phenol foams great internal energy pollution during production and demolition
synthetic floor covering	environmental impact during production complicated recycling process
polyurethane foams and insulations	impact on ozone envelope during production impact during demolition
aluminium profiles and sheets	great energy consumption during excavation and refining of raw material

It was found that in Building B such building materials were applied twice as much. If there was a need to replace some of the applied materials with alternatives from the positions where they did not fulfill the set criteria, it would be achieved more easily in Buildings A and C since the necessary replacements could be conducted without significant effects on the structure or general functioning of the building. Evaluation also pointed out that among the applied building materials, those that showed the best ecological results were: bitumen-based damp membranes and other bitumen-based materials, ceramic, e.g. clay-based products – bricks, blocks and clay roof tiles, wood elements in general, gypsum (gypsum-based partition walls), ceramic products (floor and wall tiles), water-based paints, mineral wool (thermo insulating boards for floors and walls), terrazzo (floor covering), rubber (floor covering), thermo-insulating glazing, silicon (sealants) and steel (profiles and sheets from galvanized and stainless steel). The presence of these materials was almost equal in both model buildings B and C, while Building A had most of these materials implemented. However, apart from ceramic bricks and blocks, all the other materials and products were coverings or other finishes in the buildings. In this respect, slight advantage could be given to Buildings A and C, whose structure included ceramic and clay elements (bricks, blocks, tiles) to a great extent, unlike Building B where the presence of concrete was dominant both in its structural elements as well as in its finishing parts. Besides, it should be stressed that the EPM Manual was developed for the Dutch market and adjusted to the Dutch building practice. Therefore, some materials and building principles which are common in Serbia and differ from the practice in the Netherlands and vice versa were not evaluated properly. This indicates a need for certain adjustment of the assessment method to suit particular local needs.

The evaluation conducted according to the HBM method showed that certain building materials in all three model buildings were unacceptable considering their impact to the users' health. Therefore they are not recommended for such use. The materials from this group are:

- **vinyl-asbestos** plates, due to the content of vinyl and potentially hazardous asbestos fibers. They have toxic impact on the health of the users during usage and demolition;
- **mineral wool**, due to the content of mineral fibers which could be harmful if inhaled.

Other applied building materials fulfilled the set criteria to a great extent and therefore could be considered as absolutely harmless for the users' health as well as for the environment.

However, there is a potential hazard for the health of the users that this method did not take into account. It is the fact that reinforced concrete combined with the distribution of different installation systems, especially that of electrical installation, creates an effect of a Faraday cage, that is, there is a disturbance of the electromagnetic field in such spaces. Having this in mind, advantage was given to Building A and partly to Building C, since their building technology required the minimum use of reinforced concrete (for the purpose of seismic requirements and monolithization of connections between structural elements), while in Building B reinforced concrete was used both for structural elements and for partition elements and cladding.

When compared with the EU directives and recommendations for sustainable construction, the obtained results show that basic requirements regarding the need to apply environmentally friendly and durable materials were mostly fulfilled. In all three model buildings, the set criteria were met regarding the use of local materials, design rationalization and decrease of the need for materials (especially the use of prefabricated and semi-prefabricated ceramic and concrete products since these are local and long-lasting materials). Requirements for the application of materials from renewable resources, those that are considered ecologically friendly and healthy, or avoiding the use of dangerous materials and substances, were only partially fulfilled, mostly due to the wide application of reinforced concrete and other cement-based materials as well as materials such as PVC and asbestos, which have harmful impact on the environment and the users.

As for the **3R** analysis, the first and the second "R" criteria (reduce and re-use) showed great difference between Buildings A and C on the one side, and Building B on the other. The applied building technology and the structural system brought the model B ahead of the other two models, pointing out its advantage in overall reduction in energy and operations needed on site. The "R" analysis regarding possibilities for recycling of used materials had more or less equal results for all models. Most analyzed materials proved to be recyclable with minor environmental impact during processing. However, the greatest difference from the EU recommendations could be recognized in the application of reused and recycled materials, designing that enabled re-use (dismantling of buildings and their components), and designing that enabled recycling. In spite of the fact that both Buildings B and C exemplified prefabricated or semi-prefabricated building technology, the applied system of connections between the components practically precluded further recycling of buildings and their components. Therefore, further re-use of the components and recycling of individual materials were found to be somewhat difficult and in some cases impossible. In this respect, Building B partly fulfilled the required conditions and countered some advantage over the other two model buildings. Although it was planned and realized as a completely modular and prefabricated building, possible further reuse of its components was set to a lower level because of the applied connection system technique.

7. CONCLUSION

Generally speaking, the research results point out that in the chosen building models, the applied materials had a more or less satisfactory environmental profile. However, there are certain particularities revealed in this research. On the one hand, most building materials that were applied on the investigated models fulfilled the set requirements regarding their health impact and showed good results in this domain. On the other hand, a great number of the applied materials displayed very poor results when other potential environmental impacts, local and global, were concerned. This fact indicates possible difficulties regarding total environmental potentials of building materials since, as the research showed, the primary interest of the users is satisfied but it does not include questions of the environmental status nor the environmental impacts that materials could exert, which may have hardly predictable long-term consequences. Moreover, it was found very difficult to unify the assessment of different models considering their technology and the applied construction techniques with the same predefined criteria, especially in view of the EU parameters. In spite of positive results within the set of criteria, the overall environmental performance of the buildings could be reduced when compared to other criteria. That implicates developing complex evaluation tools and methods in order to enable qualitative overall building assessment.

However, the environmental properties of building materials, e.g. their choice and potential impact have nowadays become very important for the process of creation of sustainable urban environment. As it was demonstrated, the question of the environmental profile of a building material brings with it the entire hierarchy of facts and correlations which emphasize the complexity not only of the problem, but also of measures and procedures that should be considered in order to obtain an adequate answer. Considering the long-term consequences that building construction could have on a global level, simplified and partial observation of such a complex matter as environment friendly solutions cannot offer a comprehensive insight into the problem. It is obvious that the Serbian society is just about to face the necessity of registering and evaluating the potentially harmful impacts that building materials could have on the environment as a result of activities in the building sector of its economy. In the future, this should lead towards changes in attitude regarding the construction technology of our buildings, but also regarding more thorough choice of building materials that are used for this purpose. It could be also concluded that the critical evaluation of the ecological profile of building materials should take into consideration particularities of Serbian or any given society. This requires certain modifications of the existing evaluation tools and their adjustment to the local needs. Building trends, legislation and norms, particularities of local building industries and the local climate are some of the parameters which should be considered during the required adjustment of possible local tools.

Finally, although this research offers certain ideas about the situation in our building industry regarding the environmental profile of the applied building materials and products, it should be considered as a mere starting point of much wider research. One of the future steps should be translating the obtained results from the level of building material to the level of the building, which represents a totality in which impacts from each of its integral parts are gathered and superposed. This should be one of the primary problems in the future that requires our maximal attention and awareness.

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