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Note from the Editor-in-Chief

Dear readers,

it is my great pleasure to present you with this year's fourth issue of **Tehnički Glasnik-Technical Journal**, number 4, year 12. Therefore, we have finished our 12th year of the regular publishing process, a year in which we published 43 quality papers from various scientific areas and various parts of the world. To be more precise, we have published 24 original scientific papers, 8 preliminary communications, 5 subject reviews and 6 professional papers.

With the support of the Croatian Ministry of Science and Education and the approval of the NSK Governing Board, on 1 June 2017, the National and University Library in Zagreb established the Croatian DOI Office. This establishment represents another step forward in the transition of the Library's operations into the digital environment, enabling a better promotion of Croatian publishers and an increased visibility of Croatian authors and their work in international systems and databases. Furthermore, the Office's establishment and a resulting better coordination in the deposit of data will produce significant cost reductions, since inclusion in the DOI system will now require the payment of a single annual registration fee for all publishers in Croatia, as opposed to individual annual registration fees that have so far been required from each publisher. The role of the Office is principally the management of DOI-related administrative operations such as publisher registration, paying for DOI services on behalf of Croatian publishers, providing technical support and organising promotion of the system with the support of the *CrossRef* registration agency. All journals requesting their DOIs through the Croatian DOI Office will have the Croatian Ministry of Science and Education cover all the related expenses.

In the initial phase of its activity, the Croatian DOI Office will make preparations for the signing of the contract with the *CrossRef* registration agency, complete the development and testing of the DOI administration and technical support system and establish cooperation with the University of Zagreb Computing Centre (SRCE) and the Croatian Portal of Scientific Journals (HRČAK) in order to facilitate the activities of all participants involved in DOI-related activities and to ensure the Office's maximum operational efficiency. The Office started working with publishers in early 2018.

Based on the completed applications, **Tehnički Glasnik-Technical Journal** has been found to fit all the necessary benchmarks. By signing the Contract with PILA (CrossRef) and the National and University Library in Zagreb by the Rector of University North, we became a member of *CrossRef* by intermediation of the Croatian DOI Office at the end of June 2018.

DOI, Digital Object Identifier, is an object identifier standardised as ISO 26324:2012 by the International Organization for Standardization which is used for the unique identification of a wide range of digital objects. Its advantage in relation to other identifiers in the digital environment is that it serves as a permanent link to any discrete particle of electronic content and makes possible the cross-referencing of its bibliographic records.

The DOI system is managed by the International DOI Foundation (IDF). Scientific resources are assigned DOIs through *CrossRef*, a non-profit membership organisation focusing its efforts on identifying published scientific material. *CrossRef* acts on behalf of another non-profit organisation, Publishers International Linking Association (PILA).

In our case, DOI is awarded to scientific and scientific-professional papers, namely: original scientific papers, preliminary communications, subject reviews and professional papers.

DOI consists of the domain (https//doi.org), prefix (10.31803) and suffix (tg-20181004003142). The suffix we take over from the paper ID in our system PST. For example,

one DOI for a paper published in this issue has the following format:

https://doi.org/10.31803/tg-20181004003142

As I wrote in the first issue of this volume, since January 2018, our journal has been indexed and abstracted in the Emerging Sources Citation Index (ESCI) under the Web of Science Core Collection (WoS), with the entire 2016 included in the ESCI. For that reason, it is our obligation to continue maintaining quality and working on citations so that in 2019 we could obtain the journal's first impact factor (IF) for 2018 in Journal Citation Reports (JCR).

In order for the journal to be included in some other index databases (e.g. INSPEC, Scopus, Ei Compendex, etc.), much work needs to be done regarding the Editorial Board and the International Editorial Council, as well as the membership in CrossRef which enables the use of the DOI numbers and also brings other benefits.

Throughout this year, we have strengthened the International Editorial Council with two ladies: Professor Dr. Catherine Monková from the Faculty of Manufacturing Technologies with the seat in Prešov – Technical University in Košice (Slovak Republic) and Professor Dr. Berenika Hausnerová from the Tomas Bata University in Zlín (Czech Republic). I honestly think that their membership will significantly contribute to the promotion of the journal in their scope of work.

With great efforts of the authors, reviewers and the editorial team, we have managed to complete this year's first journal issue with ten selected papers. Following the reviewers' remarks, the authors edited the papers in the form in front of you.

In the end, as always, we welcome you, our dear readers, to use your input to contribute to our joint work and permanent endeavour to retain the quality of our joint journal.

Best regards,

Full Prof. Milan Kljajin, Ph.D.
Editor-in-Chief
Tehnički Glasnik-Technical Journal

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Original scientific paper

CALCULATION OF DISPLACEMENTS AND STRESSES IN CYLINDRICAL SHELLS BY THE BOUNDARY ELEMENTS METHOD

Aleksej ANISKIN, Viktor F. OROBEY, Leonid V. KOLOMIETS, Aleksandr M. LYMARENKO

Abstract: The application of the boundary element method to the calculation of a closed circular cylindrical shell of step-constant thickness, loaded over the entire surface by a uniform normal pressure, is described. The numerical example is considered. The results of the calculation are compared by two numerical methods – boundary and finite elements.

Keywords: cylindrical shells of piecewise constant rigidity; finite element method; MATLAB; non-conservative problems of stability; numerical-analytical boundary element method; rod system; stress-strain state

1 INTRODUCTION

The majority of the problems of construction mechanics associated with the study of the stress-strain state (SSS) of designs and their elements are reduced, as a rule, to one or several differential equations. Accurate solutions of these equations, namely the solutions in a closed form, cannot always be obtained. In this regard, for the solving of many practical problems, approximate methods of research are used.

Presently, the most developed numerical method is the finite element method (FEM). The search for alternative approaches had led to the emergence of a new method, or rather, to the emergence of the boundary element method (BEM). Here, the whole area under consideration is not subjected to discretization, as opposed to the finite element method, but only its boundary. Considerable numbers of works are devoted to this direction in the field of structural mechanics. However, many problems remain unresolved. One of these problems is the calculation of shells.

2 ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

A great variety of engineering tasks in construction requires the attraction of effective methods for their calculation. Since researchers are not always satisfied with the results of FEM, it is extremely necessary to apply accurate and perfect methods for the calculation and analysis of engineering structures, in particular of cylindrical shells.

The literature on the research of cylindrical shells is very voluminous. However, there is no research where a modern numerical-analytical variant is applied [1-5]. Basically, the numerical-analytical version of BEM is developed for rod and plate systems [6-11].

At the same time, with insignificant resources (memory and speed), BEM allows engineers to obtain very accurate values of the stress-strain state of various engineering constructions. In this connection, the application and obtaining of mathematical models for various variants of BEM is an actual problem in calculations, modeling and designing of existing engineering constructions.

3 THE PURPOSE OF THE WORK

The purpose of this research is the construction of mathematical models of the state of cylindrical shells of piecewise constant rigidity that are suitable for the application of the numerical-analytical variant of BEM. Calculations of the stress-strain state of the cylindrical shells of BEM and FEM (ANSYS) are performed and their results are compared (MATLAB).

4 MAIN PURPOSE OF THE ARTICLE

Let us consider the bending of the closed circular cylindrical shell of step-constant thickness, loaded over the entire surface by the uniform normal pressure intensity p (Fig. 1).

In view of the symmetry of the load p relative to the shell axis, the deformation of the latter will also be symmetric. The bending of such a shell can be characterized by the bending of a beam-strip of unit width separated from the shell under consideration by two meridional planes (Fig. 2).

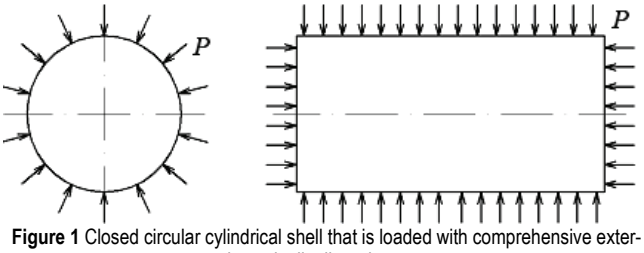

Figure 1 Closed circular cylindrical shell that is loaded with comprehensive external evenly distributed pressure

In view of the symmetry of the load p with respect to the shell axis, the deformation of the latter will also be symmetric. The bending of such a shell can be characterized by the bending of a beam-strip of unit width, separated from the shell under consideration by two meridional planes (Fig. 2).

The following will act on the beam-strip:

a) the transverse load p uniformly distributed along the length;
b) T_2 forces applied to the lateral faces of the beam-strip and characterizing the effect of the cut off part of the shell.

The forces of T_2 are directed tangentially to the circumference of the cross section of the shell;

c) longitudinal forces T_2, caused by the action of normal pressure on the end bulkheads of the shell.

Since the angle between the meridional cross sections of a beam-strip of unit width (Fig. 2a) is equal to $d\theta = \frac{1}{r}$, then the resultant of the forces T_2 is $\frac{T_2}{r}$ and the total intensity of the transverse load of the beam-strip is $p_1 = p + \frac{T_2}{r}$.

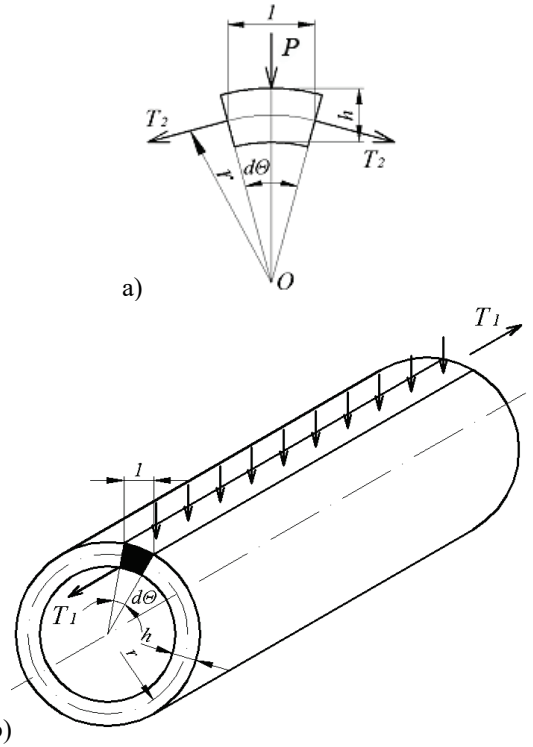

Figure 2 To the derivation of the differential equation of the axisymmetric bending of a circular cylindrical shell

Since this beam-strip, in addition to the lateral load is also subject to the action of longitudinal forces T_1, the differential equation of the bending of such a beam-strip will then be written in the following form:

$$D\frac{\mathrm{d}^4 w}{\mathrm{d}x^4} - T_1\frac{\mathrm{d}^2 w}{\mathrm{d}x^2} = p_1, \text{ or}$$

$$D\frac{\mathrm{d}^4 w}{\mathrm{d}x^4} - T_1\frac{\mathrm{d}^2 w}{\mathrm{d}x^2} = p + \frac{T_2}{r}, \tag{1}$$

where: $D = \frac{Eh^3}{12(1-\nu^2)}$ - cylindrical rigidity; ν - Poisson's ratio.

The force T_1 can be expressed through the external pressure p, acting on the end diaphragms of the shell and causing compression of the shell along the generator. It is obvious that

$$T_1 = -\frac{\pi r^2 p}{2\pi r} = -\frac{\pi r}{2}. \tag{2}$$

According to Hooke's law, for a plane stressed state, we can write that

$$\varepsilon_2^0 = \frac{1}{Eh}(T_2 - \nu T_1), \tag{3}$$

where ε_2^0 - the linear deformation of the middle surface of the shell in the direction of the tangent to its circumference.

With symmetrical deformation, the shell receives some uniform compression, which is accompanied by a decrease in the radius of the curvature of the shell by the amount w. The linear deformation of the middle surface of the shell is then determined from the obvious dependence

$$\varepsilon_2^0 = \frac{2\pi(r-w) - 2\pi r}{2\pi r} = -\frac{w}{r}. \tag{4}$$

The eliminating from (3) with the help of (4) the quantity ε_2^0 and solving the resulting equation with respect to T_2 helps us obtain the following:

$$T_2 = \nu\, T_1 - Eh\frac{w}{r}. \tag{5}$$

Using the obtained dependences (2) and (5), we exclude the forces T_1 and T_2 from the Eq. (1).We get the following:

$$D\frac{\mathrm{d}^4 w}{\mathrm{d}x^4} + \frac{pr}{2}\frac{\mathrm{d}^2 w}{\mathrm{d}x^2} + \frac{Eh}{r^2}w = p\left(1 - \frac{\nu}{2}\right). \tag{6}$$

The last equation determines the elastic surface of a circular cylindrical shell bounded at its ends by end diaphragms and loaded with uniform external pressure.

The differential Eq. (6) in its structure represents the equation of the bending of a prismatic beam of the inflexibility $EI = D$, lying on a solid elastic base stiffness with the inflexibility

$$k = \frac{Eh}{r^2}, \tag{7}$$

loaded uniformly distributed load with the intensity

$$q = p\left(1 - \frac{\nu}{2}\right) \tag{8}$$

and the longitudinal force

$$T = -\frac{pr}{2}. \tag{9}$$

In the notation (7) - (9), equation (6) can be rewritten in the form

$$EIw^{IV} - Tw'' + kw = q. \tag{10}$$

The Eq. (10) and possible forms of its general integral are well-known. The form of the general integral is determined by the numerical value of the parameter β:

$$\beta = \frac{T}{2\sqrt{EIk}}. \tag{11}$$

For the shells of greatest practical interest, the parameter β satisfies the condition $0 < \beta^2 < 1$. The general integral of the Eq. (10), or equivalently, of the Eq. (6) can then be written in the form

$$\begin{aligned} w(x) = {} & C_1 \mathrm{ch}\delta x \cos\gamma x + C_2 \mathrm{ch}\delta x \sin\gamma x + \\ & + C_3 \mathrm{sh}\delta x \cos\gamma x + C_4 \mathrm{sh}\delta x \sin\gamma x + w_{\text{part}}, \end{aligned} \tag{12}$$

where

$$\delta = \alpha\sqrt{1+\beta}; \quad \gamma = \alpha\sqrt{1-\beta}; \quad \alpha = \sqrt[4]{\frac{k}{4EI}}. \tag{13}$$

As $p = const$, the particular solution is determined by the formula

$$w_{\text{part}} = \frac{q}{k} = \frac{pr^2}{Eh}\left(1 - \frac{\nu}{2}\right). \tag{14}$$

A closed cylindrical shell, bounded at its ends by transverse diaphragms, cannot perceive large external transverse pressures if the distance between the diaphragms is sufficiently large. Such a shell can lose stability even at a very low value of external pressure.

The most effective means of increasing the stability of cylindrical shells is their reinforcement with annular closed stiffeners.

In connection with this, consider the work on the bending of a closed cylindrical circular uniformly loaded shell, reinforced between transverse diaphragms by equidistant identical annular ribs of the area A (Fig. 3).

Neglecting the influence of the stiffness of the end diaphragms on the work in the middle part of the shell, we can assume that the radial compressions of the shell at a certain distance from the diaphragms will be symmetrical with respect to the plane of the reinforcing ribs. By virtue of this, we can confine ourselves to examining the bending of the shell only within one span.

If we place the origin of coordinates in the middle between the edges (Fig. 4), then, because of the symmetry of the shell bending relative to the chosen origin in the expression (12), only even terms should be retained, that is, take the form of $C_2 = C_3 = 0$.

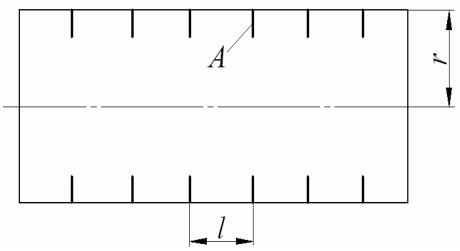

Figure 3 Scheme of a circular cylindrical shell reinforced with identical equidistant annular ribs

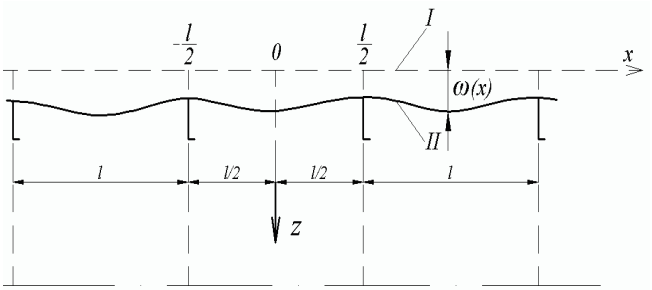

Figure 4 To the formulation of the boundary conditions of a circular cylindrical shell reinforced by ribs

Expression (12) takes the form

$$w(x) = \frac{pr^2}{Eh}\left(1 - \frac{\nu}{2}\right) + C_1 \mathrm{ch}\delta x \cos\gamma x + C_4 \mathrm{sh}\delta x \sin\gamma x. \tag{15}$$

In view of the symmetry of the elastic shell surface relative to the plane of each of the reinforcing ribs, the angles of the rotation of the shell on the edges will be zero, i.e. with

$$x = \pm\frac{l}{2}$$

$$\frac{\mathrm{d}w}{\mathrm{d}x} = 0. \tag{16}$$

The second boundary condition is obtained if we consider the interaction of the shell and the reinforcing edge.

When acting on the pressure shell p, the edge is exposed from the shell side to the action of a uniformly distributed load with the running intensity p_1. The linear load p_1 is balanced by twice the value of the transverse force in the reference section of a beam-strip of unit width, i.e.

$$p_1 = 2D\left.\frac{\mathrm{d}^3 w}{\mathrm{d}x^3}\right|_{x=\frac{l}{2}}. \tag{17}$$

The voltage value σ_p, acting in the cross section of the edge, can be determined, on the one hand, from the obvious equality

$$\sigma_p = -\frac{p_1 r}{A}, \tag{18}$$

or on the other hand, by the formula

$$\sigma_p = -\frac{w\left(x=\frac{l}{2}\right)}{r}E. \tag{19}$$

From the comparison of (18) and (19), we obtain

$$p_1 = -\frac{w\left(x=\frac{l}{2}\right)}{r^2}EA. \tag{20}$$

Eliminating p_1 with (20) from (17), we obtain the second missing boundary condition for determining the integration constants in the expression (15):

$$w\Big|_{x=\frac{l}{2}} = \frac{2Dr^2}{EA}\frac{\mathrm{d}^3 w}{\mathrm{d}x^3}. \tag{21}$$

Substituting the expression for the x from (15) into the boundary conditions (16) and (21), we obtain two equations, the joint solution of which allows us to determine the unknown C_1 and C_4:

$$\begin{cases} C_1 = -\dfrac{2pr^2}{Eh}\left(1-\dfrac{\nu}{2}\right)\dfrac{u_1 \mathrm{ch}u_1 \sin u_2 + u_2 \mathrm{sh}u_1 \cos u_2}{u_2 sh2u_1 + u_1 \sin 2u_2}\varepsilon_1; \\ C_4 = -\dfrac{2pr^2}{Eh}\left(1-\dfrac{\nu}{2}\right)\dfrac{u_2 \mathrm{ch}u_1 \sin u_2 - u_1 \mathrm{sh}u_1 \cos u_2}{u_2 \mathrm{sh}2u_1 + u_1 \sin 2u_2}\varepsilon_1, \end{cases} \tag{22}$$

where

$$\begin{aligned} &\varepsilon_1 = \frac{1}{1+\dfrac{lh}{A}A_1(u_1,u_2)}; \\ &A_1(u_1,u_2) = \sqrt{1-\beta^2}\,\frac{\mathrm{ch}2u_1 - \cos 2u_2}{u_2 \mathrm{sh}2u_1 + u_1 \sin 2u_2}; \\ &u_1 = \frac{\delta l}{2} = u\sqrt{1+\beta}; \quad u_2 = \frac{\gamma l}{2} = u\sqrt{1+\beta}; \\ &u = 0{,}6425\frac{l}{\sqrt{rh}}. \end{aligned} \tag{23}$$

With the final expression for $w(x)$, we can determine all elements of the beam-bending strip and, consequently, the shell elements under consideration bending.

The foregoing solution of the problem takes into account the influence of longitudinal forces on the bending of the shell. However, as numerical calculations show, in most cases, this influence can be neglected. Instead of (10), we should then consider an equation of the form

$$EIw^{IV} + kw = q. \tag{24}$$

As it can be seen from the differential Eq. (24) and the boundary conditions (16) and (21), the approximate solution reduces to solving the problem of the bending of a single-span beam, lying on an elastic foundation loaded with a uniformly distributed load and rigidly embedded at the ends on elastic supports with a compliance coefficient k_{Π}, equal to

$$k_{\Pi} = \frac{2r^2}{EA}. \tag{25}$$

The final formulas for determining the characteristic elements of the bending of the beam-strip, and, consequently, of the shell as a whole, are written in the following form:

The deflection of the shell in the cross-section between the ribs

$$w(0) = \frac{pr^2}{Eh}\left(1-\frac{\nu}{2}\right)\left[1-\frac{\phi_1(u)}{1+B_1}\right]; \tag{26}$$

The bending moment in the cross-section in the middle of the span

$$M_1(0) = -\frac{pl^2}{24}\left(1-\frac{\nu}{2}\right)\frac{\chi_1(u)}{1+B_1}; \tag{27}$$

The bending moment in reference sections

$$M_1\left(\frac{l}{2}\right) = \frac{pl^2}{12}\left(1-\frac{\nu}{2}\right)\frac{\chi_2(u)}{1+B_1}; \tag{28}$$

The deflection of the shell in the reference section

$$w\left(\frac{l}{2}\right) = \frac{pr^2}{Eh}\left(1-\frac{\nu}{2}\right)\frac{B_1}{1+B_1}. \tag{29}$$

Here $B_1 = \dfrac{lh}{E}\mu_1(u)$, $\varphi_1(u), \chi_1(u), \chi_2(u)$, $\mu_1(u)$ - tabulated functions.

In engineering practice, there are cases when the elastic rod system is in contact with an elastic base. The calculation of such a system must be supplemented by a rod scheme on an elastic base. The simplest and most widely used design scheme is the *E*. Winkler model – single-bed scheme. The simplicity of this model leads to inadequate accuracy of the results obtained. Therefore, more perfect and accurate models were later developed.

The Cauchy problem for a model with two bed coefficients is represented in the form

$$
\begin{aligned}
&Dv^{IY}(x)+\frac{pr}{2}v''(x)+\frac{Eh}{r^2}v(x)=p\left(1-\frac{\mu}{2}\right);\\
&v(0);\ \ \varphi(0)=v'(0);\\
&M(0)=-D\,v''(0)-T\,v(0);\\
&Q(0)=-D\,v'''(0)-T\,v'(0);\\
&T=-\frac{pr}{2}.
\end{aligned}
\tag{30}
$$

The characteristic equation for the differential Eq. (30) is a biquadratic:

$$
\begin{aligned}
&Dk^4+\frac{pr}{2}k^2+\frac{Eh}{r^2}=0,\quad k^2=t;\\
&Dt^2+\frac{pr}{2}t+\frac{Eh}{r^2}=0,
\end{aligned}
\tag{31}
$$

which roots

$$
\begin{aligned}
&t_{1,2}=\frac{-\frac{pr}{2}\pm\sqrt{\left(\frac{pr}{2}\right)^2-4D\frac{Eh}{r^2}}}{2D};\\
&k_{1,2,3,4}=\pm\sqrt{\frac{-\frac{pr}{2}\pm\sqrt{\left(\frac{pr}{2}\right)^2-4D\frac{Eh}{r^2}}}{2D}}.
\end{aligned}
\tag{32}
$$

The fundamental orthonormal functions of the task for all four possible variants of the roots of the characteristic equation are known [1].

Variant 1. Roots are complex (corresponds to low pressures):

$$k_{1,2,3,4}=\pm a\pm ib, \tag{33}$$

where

$$
\begin{aligned}
&a=\alpha\sqrt{1+\beta};\\
&b=\alpha\sqrt{1-\beta};\\
&\alpha=\sqrt[4]{\frac{k}{4D}};\\
&\beta=-\frac{\frac{pr}{2}}{2\sqrt{Dk}}.
\end{aligned}
\tag{34}
$$

Variant 2. Imaginary roots:

$$k_{1,2}=\pm ia;\ \ k_{3,4}=\pm ib. \tag{35}$$

This variant of the roots also corresponds to the compression of the shell.

Variant 3. Four valid roots:

$$k_{1,2}=\pm a;\ \ k_{3,4}=\pm b. \tag{36}$$

This variant of the roots corresponds to the extension of the shell.

Variant 4. Two real roots and two imaginary roots:

$$k_{1,2}=\pm a;\ \ k_{3,4}=\pm ib. \tag{37}$$

This variant of the roots also corresponds to the extension of the shell.

5 RESULTS

As an example, consider a cylindrical shell rigidly clamped along the ends of step-constant rigidity, which is under the action of uniform internal pressure (Fig. 5).

The algorithm for calculating of the cylindrical shell is:

1. Break the shell into three modules.
2. We form the matrices of the initial and final parameters and the load vector, taking into account the boundary conditions, the equilibrium equations and the equations of the compatibility of displacements of the nodes 1 and 2.

An analysis of the matrix $\boldsymbol{X}_*$ shows that in the matrix $\boldsymbol{A}_*$, it is necessary to zero the first and second columns and then introduce compensating elements for transferring the final parameters from $\boldsymbol{Y}$ to the matrix $\boldsymbol{X}_*$.

3. The equation of the boundary value problem for a cylindrical shell by the boundary element method takes the form (38).
4. By solving the system (38) in the MATLAB environment, we obtain numerical and visual parameters of the stress-strain state of the shell.
5. In accordance with the algorithm above, the cylindrical shell of step-constant rigidity is calculated for the action of internal pressure (Fig. 5).

$$\boldsymbol{X}_* = \begin{bmatrix} D_1v^{0-1}(0)=0;\ M^{2-3}(l_3) \\ D_1\varphi^{0-1}(0)=0;\ Q^{2-3}(l_3) \\ M^{0-1}(0) \\ Q^{0-1}(0) \\ D_2v^{1-2}(0) \\ D_2\varphi^{1-2}(0) \\ M^{1-2}(0) \\ Q^{1-2}(0) \\ D_3v^{2-3}(0) \\ D_3\varphi^{2-3}(0) \\ M^{2-3}(0) \\ Q^{2-3}(0) \end{bmatrix} \quad \boldsymbol{Y} = \begin{bmatrix} D_1v^{0-1}(l_1)=D_1v^{1-2}(0) \\ D_1\varphi^{0-1}(l_1)=D_1\varphi^{1-2}(0) \\ M^{0-1}(l_1)=M^{1-2}(0) \\ Q^{0-1}(l_1)=Q^{1-2}(0) \\ D_2v^{1-2}(l_2)=D_2v^{2-3}(0) \\ D_2\varphi^{1-2}(l_2)=D_2\varphi^{2-3}(0) \\ M^{1-2}(l_2)=M^{2-3}(0) \\ Q^{1-2}(l_2)=Q^{2-3}(0) \\ D_3v^{2-3}(l_3)=0 \\ D_3\varphi^{2-3}(l_3)=0 \\ M^{2-3}(l_3) \\ Q^{2-3}(l_3) \end{bmatrix} \quad \boldsymbol{B} = \begin{bmatrix} -B_{11}^{0-1}(l_1) \\ -B_{21}^{0-1}(l_1) \\ B_{31}^{0-1}(l_1) \\ B_{41}^{0-1}(l_1) \\ -B_{11}^{1-2}(l_2) \\ -B_{21}^{1-2}(l_2) \\ B_{31}^{1-2}(l_2) \\ B_{41}^{1-2}(l_2) \\ -B_{11}^{2-3}(l_3) \\ -B_{21}^{2-3}(l_3) \\ B_{31}^{2-3}(l_3) \\ B_{41}^{2-3}(l_3) \end{bmatrix}$$

	1	2	3	4	5	6	7	8	9	10	11	12			
1			$-A_{13}$	$-A_{14}$	$-\frac{D_1}{D_2}$								$M^{2-3}(l_3)$		$-B_{11}^{0-1}(l_1)$
2			$-A_{23}$	$-A_{24}$		$-\frac{D_1}{D_2}$							$Q^{2-3}(l_3)$		$-B_{21}^{0-1}(l_1)$
3			A_{33}	A_{34}			-1						$M^{0-1}(0)$		$B_{31}^{0-1}(l_1)$
4			A_{43}	A_{44}				-1					$Q^{0-1}(0)$		$B_{41}^{0-1}(l_1)$
5					A_{11}	A_{12}	$-A_{13}$	$-A_{14}$	$-\frac{D_2}{D_3}$				$D_2v^{1-2}(0)$		$-B_{11}^{1-2}(l_2)$
6					A_{21}	A_{22}	$-A_{23}$	$-A_{24}$		$-\frac{D_2}{D_3}$			$D_2\varphi^{1-2}(0)$		$-B_{21}^{1-2}(l_2)$
7					$-A_{31}$	$-A_{32}$	A_{33}	A_{34}			-1		$M^{1-2}(0)$		$B_{31}^{1-2}(l_2)$
8					$-A_{41}$	$-A_{42}$	A_{43}	A_{44}				-1	$Q^{1-2}(0)$		$B_{41}^{1-2}(l_2)$
9									A_{11}	A_{12}	$-A_{13}$	$-A_{14}$	$D_3v^{2-3}(0)$		$-B_{11}^{2-3}(l_3)$
10									A_{21}	A_{22}	$-A_{23}$	$-A_{24}$	$D_3\varphi^{2-3}(0)$		$-B_{21}^{2-3}(l_3)$
11	-1								$-A_{31}$	$-A_{32}$	A_{33}	A_{34}	$M^{2-3}(0)$		$B_{31}^{2-3}(l_3)$
12		-1							$-A_{41}$	$-A_{42}$	A_{43}	A_{44}	$Q^{2-3}(0)$		$B_{41}^{2-3}(l_3)$

(38)

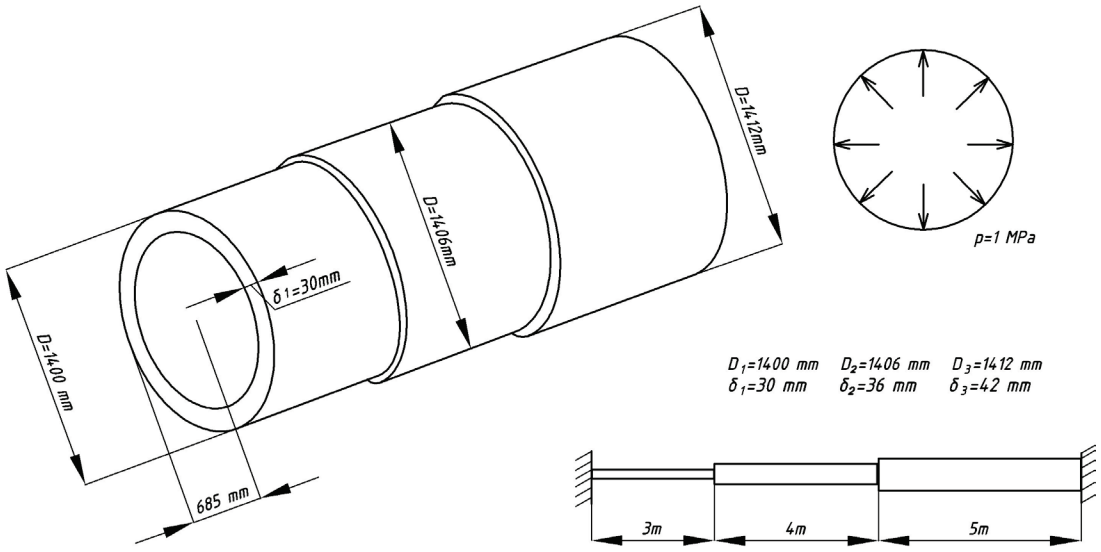

Figure 5 Cylindrical shell of step-constant stiffness

With the indicated shell parameters, the characteristic equation (30) for each section with constant rigidity has, as in the previous problem, complex roots:

- On a section with the diameter D_1

$$k_{1-4} = \pm(0{,}0899 \pm i \cdot 0{,}0895),$$

- On a section with the diameter D_2

$$k_{1-4} = \pm(0{,}0819 \pm i \cdot 0{,}0818),$$

- On a section with the diameter D_3

$$k_{1-4} = \pm(0{,}0758 \pm i \cdot 0{,}0757),$$

i.e. where a solution for the fundamental functions and the load vector are used for the **Variant 1**.

Because of the calculations in the MATLAB environment, the values of deflections, angles of rotation, bending moments, transverse forces and stresses are calculated. The numerical values of deflections and stresses, which are calculated with a step of 1m at the points of the upper formed shell, are given in Tab. 1.

Table 1 Stresses and displacements in a shell of variable rigidity

Coordinate along the axis, m	BEM, MATLAB		FEM, ANSYS	
	Stress, MPa	Displacement, m	Stress, MPa	Displacement, m
1	20.828	0.07419	20.754	0.07132
2	20.731	0.07399	20.751	0.07130
3	19.029	0.06867	19.01	0.00162
4	17.353	0.06294	17.415	0.07139
5	17.377	0.06298	17.415	0.07130
6	17.395	0.06301	17.415	0.07130
7	16.021	0.05814	16.183	0.00162
8	15.026	0.05411	15.034	0.07140
9	15.033	0.05412	15.033	0.07130
10	15.037	0.05414	15.033	0.07130
11	14.974	0.05432	15.023	0.07139

In order to verify the results of the calculation using the MGE algorithm, the problem was solved in the ANSYS package.

Here, as in MATLAB, the values of deflections, angles of rotation, bending moments, transverse forces and stresses are calculated. The numerical values of deflections and stresses, which are calculated with a step of 1m at the points of the upper shell generatrix, are given in Tab. 1.

6 CONCLUSIONS

A comparison of the stresses and displacements which were calculated by two methods (MGE and MCE) shows their good convergence (the discrepancy is 4-5%).

This paper proves that in calculating the stress-strain state of cylindrical shells of step-constant rigidity, one can use CA MGE. In this case, the resolving equation of MGE is very minimal in magnitude (in the example of 12 equations). A similar FEM equation contains about 1000 equations with a very small difference in the results.

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Original scientific paper

ESTIMATION OF ELECTRONIC PROGRAMME GUIDE USE BEHAVIOUR BASED ON THE SWITCHING COST EVALUATION

Domagoj FRANK, Ivan BUDIMIR, Marin MILKOVIĆ

Abstract: In this article we define a new technology acceptance research model which considers the comparison of two technology solutions that an individual can use. The model estimates the usage of the observed solution based on the cost of switching from the reference solution (typically a standard or older solution) to the observed solution, considering the fact that the cost of switching is caused by a difference of facilitating conditions, habit and the intention to use between the reference and observed solutions. For evaluation purposes, we observed the costs of switching from teletext use to the use of the electronic programme guide (EPG on the subset of n = 82 respondents and interpreted 77.2% of the variance, which demonstrates the high quality of the model. Evaluation results indicate that the primary obstacle to switching from teletext to EPG usage arises from the individuals' perception whether they have more or less of the necessary resources to use the EPG in comparison to the resources they have at their disposition in case of teletext use, and the second ranked switching cost is caused by a difference in habit.

Keywords: electronic programme guide; lazy user theory; switching costs; technology acceptance; teletext; UTAUT2

1 INTRODUCTION

Digitalisation of the distribution of television made the electronic programme guide (EPG) omnipresent on each television set, regardless of the distribution network type – terrestrial, satellite, cable, IPTV or the Internet. Almost every viewer has access to an EPG that provides "continuously updated information displaying scheduling information for current and upcoming programming" [1]. Research by Ericsson [2] and Nielsen [3] show that the consumption patterns of television and audio-video content are rapidly changing: consumers watch television more and more in a non-linear manner – at a time which suits them, on computers, tablets and smartphones, which allow them to watch television anywhere. Moreover, the amount of content available to the consumer is growing, which creates a problem of searching through the content and selecting it. To serve such needs, EPG application is commonly used for time-shift and content search features. Historically, the programme schedule was available in the printed form [4], either in the form of a programme schedule in the daily newspapers or in the form of a specialized magazine with a weekly programme schedule, then as information presented by teletext systems [5], and in more recent times on specialized Internet portals and mobile applications.

The study that evaluated the use of the EPG based on the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2) model [6] revealed, among other findings, that only 130 out of 234 respondents primarily select the EPG as an information source, although it is readily available on every television set, and that the total of 82 respondents still use teletext as a source of information for displaying the scheduling information. While the use of the UTAUT2 based model proved to be adequate for determining the motivators for using the EPG and explained 78% of the variance, explaining the reasons why respondents still use the legacy solution (i.e. teletext) is not possible by using the UTAUT2 model because it allows research only on a single solution or technology, disregarding the existence of all other solutions for the same individual's requirement or need. In order to consider multiple solutions to the individual's requirement, an approach similar to the Lazy User Theory would be needed [7, 8].

In this article we define a new research model which considers the comparison of two solutions that an individual can select and use. The model estimates the usage of the observed solution based on the cost of switching from the reference solution (typically a standard or older solution) to the observed solution, which would typically be based on the newer technology. For the evaluation of the model, we observe the costs of switching from teletext use to the use of EPG based on the same data set that is used in the UTAUT2 based study [6] to enable comparison of research models.

2 LAZY USER THEORY

The Lazy User Theory (LUT) tries to define a framework that would allow the studying of the behaviour of an individual (the User), taking into account his needs on the one hand and his current state on the other hand in order to choose a solution from the set of all possible solutions based on the least effort principle [7, 8]. LUT's focus is on the characteristics and needs of the user, which LUT sees as the most important factors in technology acceptance. According to LUT, the user selects a solution to meet his needs from the subset of universal (all possible) solutions, which is limited by the user's state, i.e. the current capabilities and/or circumstances surrounding the user, namely a set of solutions that are available to him and are a subset of a universal set of solutions (Fig. 1).

When choosing a solution, the user valorises the effort he or she assumes will be needed when choosing one of the solutions and selects the one that requires the least effort. Namely, LUT suggests that the user automatically applies the path of least resistance and automatically selects the solution that requires the least effort. LUT defines *user need* as "an

explicitly specifiable want that can be completely fulfilled" [8] for example in the case of an information nature need: the need for the type, depth, quality and completeness of the information and the speed of retrieving that information. *User state* refers to the conditions in which the user finds himself when he has a need, i.e. needs a particular product, information or service. Those conditions vary depending on the user's location, available devices, time in which the need should be met, and other resources that enable the user to act. Depending on the user's state, a subset of solutions from the universal set of solutions is selected and only those that can meet the need in that specific state are retained. *Effort* is defined in the sense that it involves the necessary time, money and energy to perform a physical or mental task. It assumes that less is necessary and better, that is, that the user inevitably chooses a solution that requires less money, time or energy spent.

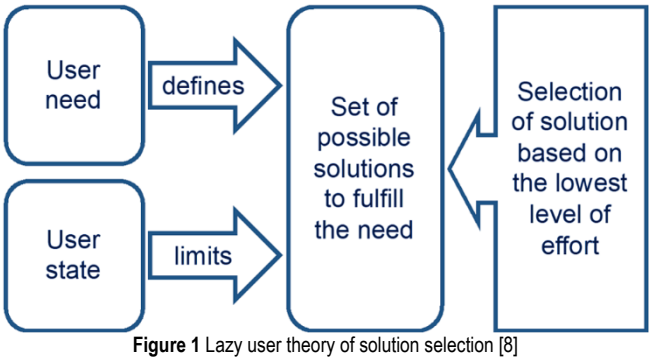

Figure 1 Lazy user theory of solution selection [8]

The Lazy User Theory introduces *switching costs* – the cost that a user estimates is generated when one has to decide whether to switch from using one solution to meet his needs to another solution. The theory uses the concepts that in 2002 Thompson and Cats-Baril [9] considered in the Information Technology and Management Theory as the cost associated with the change of suppliers. It also considers the work of Hess and Ricart from 2003 [10] that observes switching costs as an obstacle that prevents the user from switching to a competitor product or service. According to Hess and Ricart, switching costs arise from, in a broader sense, the amount of investment that the user needs to spend in order to use a solution and that includes: software licenses, relationship with the supplier, accumulated knowledge and education, cost of seeking solutions, trust, commitment, and more. Investment may be both a previous and a potential one. When choosing, the customer decides between the previous investments he has already made and potential future investments in which he is yet to invest, i.e. he has to bear a new expense. In order for the user to choose a new solution that requires additional investment, the corresponding return on the new investment must be higher than the benefits that the user enjoys due to the existing investment. Collan and Tetard note that users can also go back to the previously used solution and will, depending on their state and need, choose a solution where the switching costs are minimal. Observing the switching costs helps understand the barriers that prevent users from changing the technology they use for fulfilling their need and from triggering the change in user behaviour. As part of the switching costs, Collan and Tetard particularly emphasize learning and exercise as important factors, and they recognize four phases in the process of accepting the solution:

1. The phase before use, in which users need the information on the solution – way of use, price, ease of use, experience of others, possible disadvantages and other; and on the basis of that information, they build their expectations.
2. First use during which users compare their expectations with the real use, which results in the acceptance or rejection of the system.
3. Early use during which users build their knowledge and experience that lead them toward routine use.
4. Routine use, when users know how to use all the functions they need.

All of the mentioned learning phases are an investment that can be partially transferred (for example, if the new system has a similar interface) or may become a "sunk" cost, i.e. a non-refundable cost in the event of a transition to a new solution without returning to the old ways in the future choice of solutions.

3 COMPARISON AND THE CHARACTERISTICS OF UTAUT2 AND LUT

In 2012 Dwivedi et al. [11] categorised a comprehensive set of numerous theories and models used in the technology acceptance research, and in his further work with Williams et al., he concluded in 2015 [12] that the Unified Theory of Acceptance and Use of Technology (UTAUT) developed by Venkatesh et al. in 2003 [13] was widely used and quoted over 5000 times. Venkatesh extended of the original UTAUT model to UTAUT2 [14] by adding three new constructs in order to explain the behaviour of users-consumers. He concluded that UTAUT2 provides significantly better results in explaining the variance of the user's behavioural intention from 56% (UTAUT) to 74% (UTAUT2). For use behaviour, i.e. the actual use, UTAUT2 explained 56% of the variance in comparison to the 40% of the variance explained by UTAUT on the same set of data. In 2015, Rondan-Cataluna et al. [15] confirmed that UTAUT2, in comparison to other most popular research models, has better performance when research is conducted on end users, i.e. consumers.

UTAUT's purpose is to research the acceptance of information technology in the business environment, where information solutions are often determined by the business policy of the company. UTAUT2 puts focus on the end user, i.e. the consumer, by introducing constructs that value motivational factors related to the perceived cost-benefit, habit or enjoyment of using information technology, but it still holds on to observing only one possible solution, i.e. the use of one information technology, excluding all other possibilities and technologies that the users could select and use to solve their problems or meet their needs. LUT puts users and their needs in the focus and provides a comprehensive framework from the point of observing the

users' action in solving their need – it assumes that users can choose between all the possible solutions that can fully meet their specific need.

UTAUT2 introduces the construct of *Behavioural Intention* in the use of technology as an important factor affecting the real use of technology, while LUT includes the cultural and social circumstances that surround the user and contemplates the impact of the available resources on technology acceptance. As the basic variable in user behaviour, LUT observes the generally defined *effort* in relation to the required time, money and energy needed to perform a physical or mental task, with each user having his own function to transform those factors, and where the degree of effort depends on the user. With that type of definition, it is not possible to establish a repeatable measurement model that corresponds to the needs of the user behaviour measurement. LUT perceives effort in a broader sense as the key decision-making element in the solution selection process, while UTAUT2 precisely specifies seven constructs (Fig. 2) as the decisive factors of *Behavioural Intention (BI)* as in Eq. (1) that are also included in the "size" of the effort as perceived by LUT.

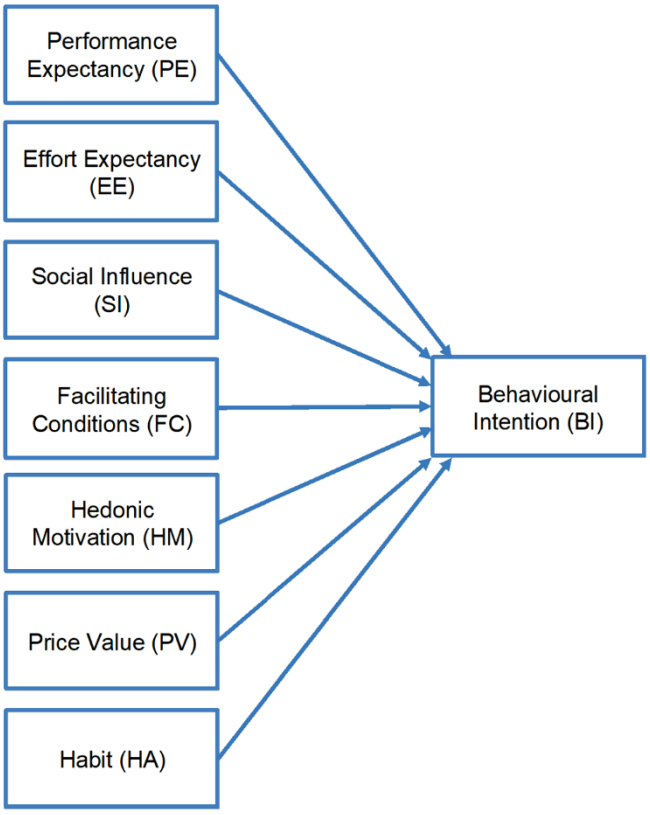

Figure 2 Model of determining Behavioural Intention (BI) according to the UTAUT2 model [14]

- *Performance expectancy (PE)* determines the user's belief that by using the solution, he will be more efficient and productive.
- *Effort expectancy (EE)* outlines the user's assessment of the effort needed to become an expert in using the solution.
- *Social influence (SI)* illustrates the individual's belief that the people surrounding him will support the use of the solution.
- *Facilitating conditions (FC)* are defined as the "degree to which the individual believes that there is an organizational and technical infrastructure that supports the use of the system". [13]
- *Hedonic motivation (HM)* determines the individual's expectation or experience that the use of the solution is pleasant or fun.
- *Price value (PV)* outlines the individual's assessment that the use of the solution will be useful in relation to the monetary compensation (e.g. good value for money).
- *Habit (HA)* determines the user's assessment of how much, when taking into consideration previous experience, the use of solution will become an everyday routine.

$$BI = f(PE, EE, SI, FC, HM, PV, HA) \quad (1)$$

In order to measure the user's behaviour, UTAUT2 defines the relation between *Use Behaviour (UB)* and three other constructs (Fig. 3) as shown in Eq. (2): *Facilitating Conditions (FC)*, *Habit (HA)* and *Behavioural Intention (BI)*.

$$UB = f(FC, HA, BI) \quad (2)$$

On a theoretical level, unlike the UTAUT2 model, LUM considers the concepts of effort, switching costs and learning, suggesting a free definition of constructs and relationships among them to the researcher, which makes LUM more of a theory than a research model

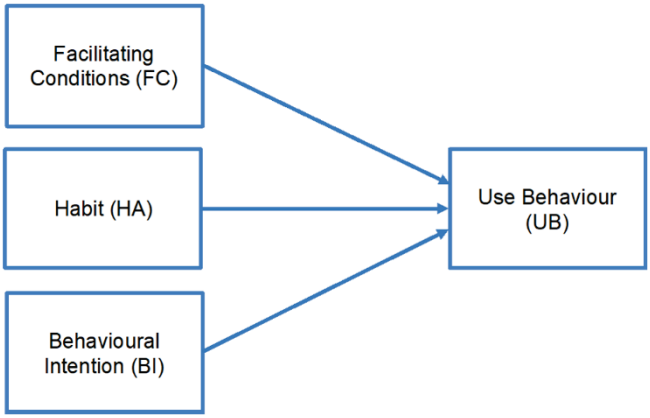

Figure 3 Model of determining Use Behaviour (UB) according to the UTAUT2 model [14]

4 SWITCHING COST RESEARCH MODEL

In a world where, in order to satisfy their needs, consumers can choose between a number of solutions, the model which could help in the research of consumer behaviour has to put its focus on the user-consumer and his free will to choose the solution that suits him best. At the same time, the model should rigorously determine its constructs in order to define a research framework that allows

repeatable measurements. The previous chapter shows that none of the existing models alone meet those criteria, but also that UTAUT2 and LUT share features that can be used to create a new model that will meet the required research requirements:

1. The model should enable the comparison of different solutions, i.e. technologies. The goal is to research the behaviour of consumers in the acceptance of the technology that is being observed. Except in the case of completely new services that have not existed so far, the consumer usually already has ways to satisfy his wishes and needs. Therefore, the model must enable the research of effort in the broader sense of the word when consumers switch from the existing behaviour (technology use) to new behaviour, i.e. the use of the technology that is being observed. LUT is a suitable model for the adoption of concepts that meet this requirement.
2. The model must enable the measuring of switching costs that the user must bear in order to switch from the existing solution to the information solution that is being observed in the research. The idea of this concept is elaborated in LUT, but UTAUT2 defines the variables and connections between them that can be adopted to meet this requirement.
3. The model should enable quantitative and repeatable measurements in order to be used to measure the changes in consumer behaviour in time, as well as for various solutions. Therefore, it is necessary to rigorously determine the constructs and relations between them, which is the requirement met by UTAUT2.

Considering the aforementioned requirements, we adopt constructs and relations between them from the UTAUT2 model, hence inheriting a large body of research and knowledge. However, according to the LUT concepts, we observe how the user relates the two possible solutions in terms of the cost of switching from the first (reference) solution to the second (observed) solution – the one that is of research interest. We define three new variables: *Facilitating Conditions Switching Costs* (SC_{FC}) as shown in Eq. (3), *Habit Switching Costs* (SC_{HA}) as in Eq. (4) and *Behavioural Intention Switching Costs* (SC_{BI}) as shown in Eq. (5) that are the differences of the variables *Facilitating Conditions*, *Habit* and *Behavioural Intention* of the reference solution and observed solution.

$$SC_{FC} = FC_R - FC_O \quad (3)$$

FC_R – *Facilitating Conditions*, reference solution
FC_O – *Facilitating Conditions*, observed solution

$$SC_{HA} = HA_R - HA_O \quad (4)$$

HA_R – *Habit*, reference solution
HA_O – *Habit*, observed solution

$$SC_{BI} = BI_R - BI_O \quad (5)$$

BI_R – *Behavioural Intention*, reference solution
BI_O – *Behavioural Intention,* observed solution

The values of *Behavioural Intention* variables are related to seven variables as defined by the UTAUT2 model (Fig. 2) and are determined separately for the reference as shown in Eq. (6) and observed solution as in Eq. (7).

$$BI_R = f(PE_R, EE_R, SI_R, FC_R, HM_R, PV_R, HA_R) \quad (6)$$

$$BI_O = f(PE_O, EE_O, SI_O, FC_O, HM_O, PV_O, HA_O) \quad (7)$$

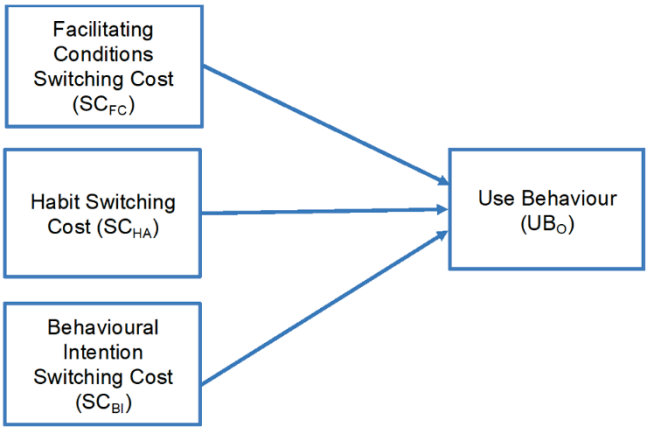

Figure 4 Switching cost research model

We then observe the influence of the three new variables on the *Use Behaviour* (UB) (Fig. 4) as in Eq. (8) variable that represents the actual use of the observed solution.

$$UB_O = f(SC_{FC}, SC_{BI}, SC_{HA}) \quad (8)$$

UB_O is the observed *User Behaviour.*

5 THE COST OF SWITCHING FROM TELETEXT TO EPG

For this analysis, the same data set was used as the one in the evaluation of electronic programme guide adoption with UTAUT2 based model [6] in order to enable research result comparison. In the data set, the respondents are users of all solutions that can be used to get information on the television programme schedule, including the electronic programme guide, printed programme guide, teletext and Internet portals and/or applications.

The total number or respondents (Tab. 1) is the largest for the electronic programme guide and equal to the total number of respondents, due to the fact that the survey logic ensured that all respondents provide answers for this solution, as it is the subject of research. The respondents that have selected the electronic programme guide as their first choice, were given the opportunity to select the secondary solution they use (2nd choice). 8 of them selected a printed programme guide, 28 teletext, 37 Internet portal or application and the rest of 57 respondents asserted that they exclusively use the electronic programme guide. A total of 104 respondents that have selected the printed programme guide, teletext or Internet portal/application as the primary solution (1st choice) were forced to provide responses also for the electronic programme guide.

The teletext is the second most widely used solution with 82 respondents, followed by the Internet portals/applications

with 73 respondents and finally, by the printed programme guides with only 22 respondents.

Table 1 Solution selection for retrieving TV programme schedule

Solution used for retrieving TV programme schedule or TV show data	Number of respondents			
	1st choice	2nd choice	Forced response	Total
Electronic programme guide	130	-	104	234
Printed programme guide	14	8	0	22
Teletext	54	28	0	82
Internet portal or application	36	37	0	73

The sample of respondents for whom we are observing the cost of switching from teletext usage to the use of the electronic programme guide is $n = 82$, i.e. 54 respondents who use teletext as the first choice and 28 primary users of the electronic programme guide, who selected teletext as their second choice (Tab. 1). 54 respondents who selected teletext as the first choice were compelled by the survey logic to answer questions about the electronic programme guide, although some of them possibly never used it.

In the evaluation of the impact of the switching cost concept, we observe the effect of the difference between the constructs defined by UTAUT2: *Facilitating Conditions (FC)* in case of Teletext usage and the same variable in the case of Electronic programme guide (EPG) usage, *Habit (HA)*, and *Behavioural Intention (BI)* to the *Use Behaviour* variable in the case of EPG usage. Therefore, we observe the aggregate *switching cost* as an effect of the three newly defined variables of *Facilitating Conditions Switching Costs* (SC_{FC}) as shown in Eq. (9), *Habit Switching Costs* (SC_{HA}) as shown in Eq. (10) and *Behavioural Intention Switching Costs* (SC_{BI}) as shown in Eq. (11) to the *Use Behaviour* (UB_{EPG}) variable for the case of using the EPG as in Eq. (12).

$$SC_{FC} = FC_{TXT} - FC_{EPG} \tag{9}$$

$$SC_{HA} = HA_{TXT} - HA_{EPG} \tag{10}$$

$$SC_{BI} = BI_{TXT} - BI_{EPG} \tag{11}$$

$$UB_{EPG} = f(SC_{FC}, SC_{BI}, SC_{HA}) \tag{12}$$

The UB_{EPG} variable has values from the subset consisting of Teletext users and which contains data collected from $n = 82$ respondents. The descriptive statistics (Tab. 2) show that the arithmetic mean obtained on the subset of Teletext users is $\mu = 4.646$, which is less than the value of the arithmetic mean of the same variable ($\mu = 5.137$), when observed on the whole sample of $N = 234$ respondents in the evaluation of EPG adoption by using the UTAUT2 model [6]. As expected, respondents in the Teletext user subset are on average less likely to use the EPG than the average of the whole set. The median of the UB_{EPG} variable is $Med = 5.500$, which is higher than its arithmetic mean. The same conclusion applies to the mod, which is $Mod = 6.000$, with the frequency of occurrence of $n = 23$ respondents of the total of $n = 82$ respondents. The variance and standard deviation as data dispersion measures are not large.

Table 2 Descriptive statistics of the Use Behaviour variable

Var.	Mean	Median	Mode	Mod Freq.	Variance	Std. dev.
UB_{EPG}	4.646	5.500	6.000	23	4.923	2.219

Table 3 Descriptive statistics of the $SC_{FC}, SC_{BI}, SC_{HA}$ variables

Var.	Mean	Median	Mode	Mod Freq.	Variance	Std. dev.
SC_{FC}	1.041	0.000	0.000	35	4.687	2.165
SC_{HA}	0.911	0.333	0.000	15	6.944	2.635
SC_{BI}	0.967	0.000	0.000	18	7.672	2.770

The arithmetic means of switching costs from teletext to the electronic programme guide are for the $SC_{FC}, SC_{BI}, SC_{HA}$ variables positive and with an approximate value of $\mu \approx 1$. This shows that, on average, all parameters show a positive cost of switching. However, the medians of all switching cost variables considerably vary from the arithmetic means. Thus, the median $Med(SC_{FC}) = 0.000$, $Med(SC_{HA}) = 0.333$ and $Med(SC_{BI}) = 0.000$, which is caused by Mode values $Mod = 0$ for all variables. This suggests that for the largest number of respondents, it is all the same whether they use teletext or the electronic programme guide. Variances and standard deviations are of the expected value, which suggests a certain dispersion of data. Therefore, the confidence intervals for the arithmetic mean are of approximate widths of 0.5 units, which implies a relatively high precision of estimating the arithmetic mean of all variables of switching costs (Tab. 4). The minimum and maximum quartiles are quite wide-ranging because the respondents have differently assigned rank variables.

Table 4 Descriptive statistics

Var.	Confidence interval lower limit -95%	Confidence interval upper limit +95%	Min	Max.	Lower quartile	Upper quartile
SC_{FC}	0.565	1.516	-2.000	6.000	0.000	1.333
SC_{HA}	0.332	1.490	-6.000	6.000	-0.333	2.667
SC_{BI}	0.359	1.576	-4.333	6.000	-0.667	2.667

The correlation analysis of the $SC_{FC}, SC_{BI}, SC_{HA}$ switching costs variables and the, SC_{HA} *User Behaviour* UB_{EPG} variable was carried out (Tab. 5).

Table 5 Correlation analysis: Pearson correlation coefficient r, p-value of variables

Var.	UB_{EPG}	SC_{FC}	SC_{HA}	SC_{BI}
UB_{EPG}	r = 1.000 p = ---			
SC_{FC}	r = -0.844 p = 0.000	r = 1.000 p = ---		
SC_{HA}	r = -0.786 p = 0.000	r = 0.739 p = 0.000	r = 1.000 p = ---	
SC_{BI}	r = -0.795 p = 0.000	r = 0.816 p = 0.000	r = 0.852 p = 0.000	r = 1.000 p = ---

All calculated Pearson correlation coefficients are statistically significant $p < 0.05$. A strong negative correlation $(-1 < r < -0{,}8)$ of $r = -0.844$ was determined in the (SC_{FC}, UB_{EPG}) pair of variables. Moreover, the correlation coefficients $r = -0.786$ and $r = -0.795$, which are on the boundary between the strong and medium

strong negative correlations $(-0.8 < r < -0.5)$, are determined for the (SC_{HA}, UB_{EPG}) and (SC_{BI}, UB_{EPG}) variable pair.

A strong positive correlation was found among the (SC_{FC}, SC_{BI}) and (SC_{HA}, SC_{BI}) pairs of variables, with the coefficients of correlation $r = 0.816$ and $r = 0.852$. A medium strong positive link exists between the (SC_{FC}, SC_{HA}) pair of $r = 0.739$. The absolute values of all established correlation coefficients are very high and indicate the existence of strong and medium strong linear relationships between variables (positive and negative).

In order to determine the influence of the switching cost variables from Teletext to EPG, a mathematical model of multiple linear regression was created. Thus, the influence of the dependent switching cost variables of $SC_{FC}, SC_{BI}, SC_{HA}$ on the independent UB_{EPG} variable was examined.

The most important assumption of linear regression is fulfilled because the dependent UB_{EPG} variable has a strong linear correlation with the independent $SC_{FC}, SC_{BI}, SC_{HA}$ variables. However, the dependent $SC_{FC}, SC_{BI}, SC_{HA}$ variables have a very strong correlation with one another, leading to the problem of multicollinearity (Table 6). This fulfils the most important assumptions necessary for the construction of a representative multiple regression model. The model itself includes the determination of the most suitable linear regression function in terms of the optimal minimum squares.

$$f: \mathbb{R}^3 \rightarrow \mathbb{R}$$

The form of the function is as shown in Eq. (13):

$$UB_{EPG} = f(SC_{FC}, SC_{BI}, SC_{HA}) + \varepsilon \quad (13)$$

Where ε is the statistical error of the estimation.

More specifically, the proposed multiple linear regression model of switching costs from teletext to an electronic programme guide is given by a linear equation as in Eq. (14):

$$UB_{EPG} = \beta_0 + \beta_1 SC_{BI} + \beta_2 SC_{FC} + \beta_3 SC_{HA} + \varepsilon \quad (14)$$

Where ε is the statistical error of the estimation.

The multiple linear regression model coefficients are calculated: β parameters, standard error of β, *t*-statistic values, and associated *p*-values.

Table 6 Correlation analysis: Pearson correlation coefficient r, p-value of variables

Var.	β	Standard error of β	$t(78)$	$p - value$
β_0	5.532	0.133	41.672	0.000
β_1	-0.067	0.097	-0.691	0.491
β_2	-0.559	0.097	-5.775	0.000
β_3	-0.262	0.088	-2.988	0.004

It was found that the β_2 and β_3 parameters of the model are statistically significant, while the β_1 parameter is not statistically significant $(p < 0.05)$. This means that the SC_{FC} and SC_{HA} variables have a statistically significant effect on the UB_{EPG} variable. The SC_{FC} variable influences the UB_{EPG} variable the most. To be more precise, increasing the value of the SC_{FC} variable for one unit causes the UB_{EPG} variable to decrease by 0.559 units. Moreover, increasing the SC_{HA} variable for one unit causes the value of the UB_{EPG} variable to decrease by 0.262 units. The remaining SC_{BI} variable is not statistically significant and does not contribute in a statistically significant manner to the UB_{EPG} variable. Furthermore, its influence is negligible with respect to the beta-coefficient of the $\beta_1 = -0.067$. The analysis of the standard beta-coefficient errors shows that they are also negligible.

The multiple regression model gives the following linear equation as a solution as shown in Eq. (15).

$$UB_{EPG} = 5.532 - 0.559SC_{FC} - 0.262SC_{HA} - 0.067SC_{BI} \quad (15)$$

Table 7 ANOVA-table of all effects of the linear regression model of variables

Statistics	Values
R	0.879
Coefficient of determination R^2	0.772
Adjusted R^2	0.764
Fisher *F*	88.180
P value of the model	0.000
Standard error of the estimate	1.079

The coefficient of determination is $R^2 = 0.772$, hence the model explains 77.2% of the variance. A very high value also belongs to the parameter $adjusted\ R^2 = 0.764$. The value of Fisher's statistics is $F = 88.180$, while the p-value is $P = 0.000$. Based on the previously presented data, p-value follows the conclusion that the coefficient of determination R^2 is statistically significant. The standard error of the estimate is very low and equals 1.079. According to all interpreted indicators, the regression model of the cost of switching from teletext to EPG adequately represents the linear link between the dependent UB_{EPG} variable and the SC_{FC}, SC_{HA} and SC_{BI} predictors.

6 CONCLUSION

Our research model defined a concept of switching costs that compares the solutions or technology pairs or competing technologies, and it used for its model evaluation an electronic programme guide as the observed solution and teletext as a reference solution. In the switching cost analysis, we created three new predictor variables: *Facilitating Conditions Switching Costs* (SC_{FC}), *Habit Switching Costs* (SC_{HA}) and *Behavioural Intention Switching Costs* (SC_{BI}), which are the differences of the *Facilitating Conditions*, *Habit* and *Behavioural Intention* variables in the case of using the electronic programme guide and their equivalents for teletext. We then observed the influence of new variables on the *Use Behaviour* (UB_{EPG}) variable that represents the use of the electronic programme guide. Arithmetic means of all variables are positive, indicating that on average, there is a positive cost of switching, which suggests that all observed parameters represented by the switching cost variables pose

an obstacle to a certain degree in the case of switching from using teletext to using the EPG. The correlation analysis further showed that all variables are highly negatively related to the use of an electronic programme guide, which is consistent with the model that says that a higher switching cost reduces the use of the solution. The regression analysis showed that the highest contribution to the cost of switching is mainly caused by the predictor variable of *Facilitating Conditions Switching Costs* (SC_{FC}) – increasing SC_{FC} for one unit decreases the EPG usage of UB_{EPG} by 0.559 units. This indicates that the main obstacle to switching from teletext to EPG arises from the individuals' perception whether they have more or less of necessary resources to use the EPG in comparison to the resources they have at their disposition in the case of teletext use. Teletext users will be more reluctant to use the electronic programme guide if they are not sure whether they will get help if they encounter a problem or if they are unfamiliar with the fact that they already have the option of using an electronic programme guide on their TV or digital receiver. Significant influence on the use of EPG is also generated from the difference in the habit of using teletext compared to the habit of using the EPG. An increase of *Habit Switching Costs* (SC_{HA}) for one unit decreases the UB_{EPG} by 0.262 units. Teletext users who are faithful to this technology seem to have deeply rooted habits and will need to use the electronic programme guide for some time before it becomes the primary choice when they want to get information on the schedule of television programs. The influence of *Behavioural Intention Switching Costs* (SC_{BI}) is not statistically significant, and its impact is negligible, which indicates that the switching cost model could be further simplified in further research.

The coefficient of determination of this model is $R^2 = 0.772$, thus it can interpret 77.2% of the variance, which demonstrates that the model has a very good representation of the switching cost caused by facilitating conditions, habit and intention to use. It is important to note that this result is achieved on the subsample of only 82 respondents, while the coefficient of determination similar to the one determined in the UTAUT2 based research equals $R^2 = 0.78$, but on a larger sample of 234 respondents.

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Original scientific paper

GREEN SUPPLY CHAIN MANAGEMENT IN CROATIAN COMPANIES

Tihomir OPETUK, Goran DUKIC, Hrvoje CAJNER, Davor KOLAR

Abstract: The scope of this paper is to present current state and trends of Green Supply Chain Management (GSCM) in Croatian companies. Due to the need for reduction of GHG emissions related to the climate change, many standards, directives, concepts, methods and models dealing with sustainability have appeared. The first part of the paper consists of an overview of GSCM where the greening diagram of GSCM is presented. The second part of the paper presents the survey which has been carried out in the Croatian business sector in view of current state and trends, barriers and drivers of the GSCM implementation. According to the results of the survey, barriers and drivers of the GSCM implementation are ranked by its significance and are compared with similar surveys carried out in the European Union (EU) and the United States of America (USA). New categorization of the drivers of the GSCM implementation is presented using the factor analysis.

Keywords: barriers; drivers; Green Supply Chain Management; survey

1 INTRODUCTION

Nowadays, the increase in greenhouse gas (GHG) emissions in the atmosphere is currently one of the most serious environmental threats. Due to GHG emissions we will be witnesses of climate change which will cause damaging impacts in the next few decades [1]. These will primarily affect the natural and human systems [2]. At the same time these emissions are also a limiting factor for the economic growth of some countries, especially those in the transition process [3]. One of the reasons for that is the protocol, adopted in 2012 at the Doha 2012 United Nation (UN) Climate Change Conference COP18 CMP8, at which the industrial world agreed to reduce the emissions of greenhouse gases approximately 18 % below 1990 levels by 2013–2020 [4]. In the meantime, also due to the climate change and the increase in environmental awareness all over the world, the concept of Green Supply Chain Management appeared. It is often defined as integrating environmental thinking into supply chain management [5]. Within that concept, many greening elements aimed at the reduction of materials, energy, waste, pollution and emissions, or promoting the usage of recyclable materials and renewable energy sources, have been introduced in various segments of supply chains. The proof lies in a number of examples from industry, as well as in significant interest of academic community that could be seen through research papers, doctoral theses and research projects.

There are three main reasons why companies implement the greening process into their corporation [6, 7, 8]:

- Legislation - they have to comply with the environmental regulations,
- Marketing - addressing the environmental concerns of their customers,
- Ecological awareness - mitigate the environmental impact of their production activities.

Today there are many concepts, methods and models which are dealing with ecology, cleaner production, greener supply chains, etc. However, the above-mentioned examples and literature are not always fully clear and identical in terms of terminology used, while those various concepts, methods and models are appearing as a topic with practically the same goal - greener processes of supply chain/production.

The first part of this paper is an overview of Green Supply Chain Management (GSCM). In addition, Life Cycle Assessment (LCA), Product Lifecycle Management (PLM), Product Life Cycle Management (PLCM) and Life Cycle Management (LCM), Green Logistics (GL), Sustainable Logistics (SL), Environmental Logistics (EL), Clean Logistics (CL) and Green Production (GP), Sustainable Production (SP), Environmental Production (EP), Clean Production (CP) are connected to sustainability and are therefore included in the research.

The research was based on the literature survey within two databases (SCOPUS and Science Direct) that contain relevant scientific journals, databases of doctoral theses, and standards and directives related to sustainable development. In addition to the above-mentioned concepts, methods and models, some standards and directives are also connected with sustainable development. Concepts of sustainable development are often associated with the following standards and directives:

- ISO 9001 Quality management systems - Requirements,
- ISO 14001 Environmental management systems - Requirements with guidance for use,
- ISO 14040 Environmental management - Life cycle assessment - Principles and framework,
- ISO 14051 Environmental management - Material flow cost accounting - General framework,
- ISO 14062 Environmental management - Integrating environmental aspects into product design and development,
- ISO 14064 Greenhouse gases - part 1, 2, 3,
- ISO 26000 Guidance on social responsibility,
- ISO 50001 Energy management systems - Requirements with guidance for use,
- OHSAS 18001 Occupational health and safety management systems,

- WEEE Waste Electrical and Electronic Equipment Directive,
- RoHS Directive on the restriction of the use of certain Hazardous substances in electrical and electronic equipment,
- IPP Integrated Product Policy,
- EuP Energy using Products Directive,
- ELV End of Life Vehicles Directive,
- EPA Environmental Protection Act,
- PPW Packaging and Packaging Waste Directive,
- EMAS Eco-Management and Audit Scheme Directive,
- VOC Volatile Organic Compounds Directive,
- ED Eco-design Directive.

The first part of the research relates to identifying interrelations among those concepts, methods and models' similarities and differences appearing in approaches of various authors, leading to an overall better understanding of the broad concept of GSCM.

The second part of the paper presents the survey which has been carried out in the Croatian business sector in view of current state and trends, barriers and drivers of GSCM.

2 GREEN SUPPLY CHAIN MANAGEMENT

From the definition of Supply Chain Management given by the Council of Supply Chain Management Professionals (CSCMP) [9], "Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities". Moreover, it includes coordination and collaboration with channel partners, i.e. suppliers, intermediaries, third party service providers and customers. In essence, supply chain management integrates supply and demand management within and across companies. Making it green, it could be simply illustrated as in Fig. 1 [7].

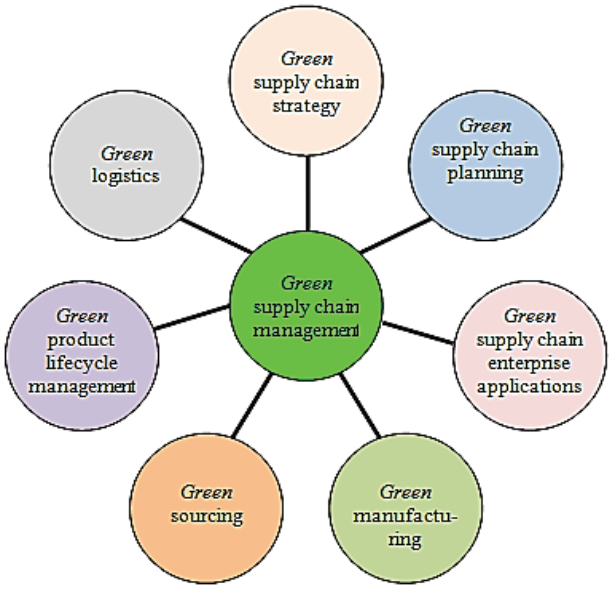

Figure 1 Elements of GSCM [7]

GSCM is a field of implementation of green thinking in all the segments of companies' activities and with focusing on the definition of SCM and three basic groups of activities - procurement, operations and logistics.

Additionally, there are many definitions of GSCM. Thus, other authors define GSCM as shown in Fig. 2 [10], Fig. 3 [11] and Fig. 4 [12]. According to the authors of this paper, green supply chain management could be illustrated as shown in Fig. 5.

As it can be seen from the Figs. 1 - 5, none of the authors are considering GSCM as suggested in this paper. This is also a new look at the GSCM concept. Also, this approach of defining the GSCM concept simplifies implementation of some GSCM models because it follows the most common classification of departments within a company.

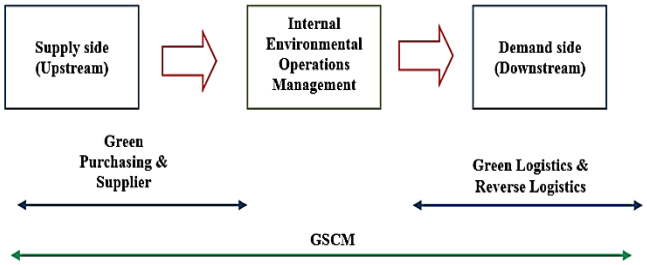

Figure 2 The GSCM concept according to Holt [10]

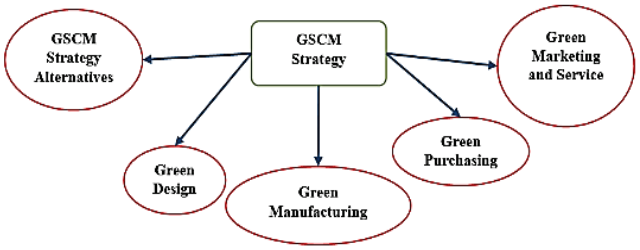

Figure 3 GSCM concept according to Chen and others [11]

Figure 4 The GSCM concept according to Kuo-Chung and others [11]

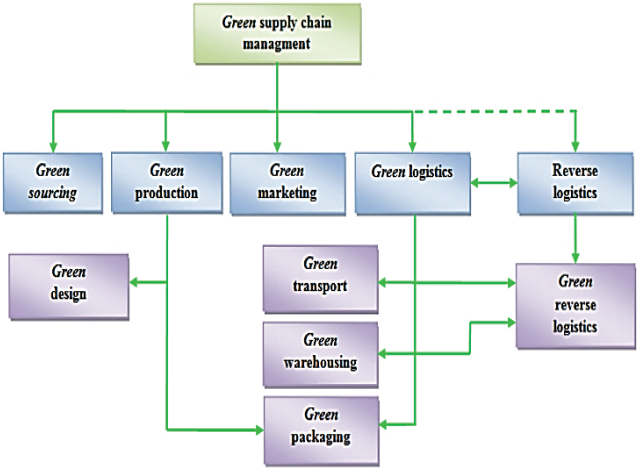

Figure 5 Greening diagram

3 DESIGN OF THE SURVEY

The GSCM topic is relatively new in Croatia and the state and trends are not precisely known, which justifies the need for such a survey. The survey was carried out in the Croatian business sector. The structure of the survey is shown in Fig. 6.

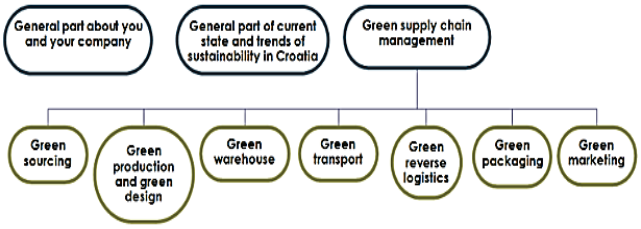

Figure 6 Structure of a business sector survey

The first part of the survey includes general questions about the examinee and the company. The second part of the survey is designed to give an insight in how well they are informed about sustainable concepts, methods, models, standards and directives and whether some of them are implemented or in the stage of implementing into the company. The third part includes questions regarding the drivers, barriers, activities and benefits of implementing GSCM. Other parts of the survey represent activities within GSCM. Total survey consists of 57 questions. In this paper, only the results of the third part of the survey (questions regarding the drivers, barriers, activities and benefits of implementing GSCM) will be analyzed.

4 RESULTS OF THE SURVEY

The invitation for the survey was sent to 3,257 big, medium and small companies of different business categories. The survey was carried out in three independent parts. The results are shown for the third part of the survey. 69 complete answers for the second part of the survey were received. The survey results [7] are presented for the Croatian companies in following parts:

- Current state of GSCM,
- Drivers for implementation of GSCM,
- Barriers for implementation of GSCM.

4.1 Current State of GSCM

As mentioned above, there are eight models within the GSCM concept. Fig. 7 shows the level of familiarity with the GSCM models, while Fig. 8 shows the level of implementation of the GSCM models within a company.

By analyzing Figs. 7 and 8, it cannot be immediately said whether there is any difference between the level of familiarity and the level of implementing the GSCM models. Because of that χ^2 test was conducted to determine the statistical significance of the differences. The result of χ^2 test for the level of familiarity with models is interesting. There are two possible conclusions here, depending on the amount of error we want to have. Thus, with the 5 % probability for an error, it can be concluded that there is a difference between the levels of familiarity with the GSCM models within a company. Also, with 10 % probability of an error, it can be concluded that there is no difference between the familiarity levels of the GSCM models within a company. The χ^2 test conducted for the level of implementation of the GSCM models within a company confirms that with 5 % probability of error there is no difference between them.

As mentioned before, there are eight models within the GSCM concept. The idea is to rank them according to the relevance and to see which of them are most relevant for Croatian companies. This has been done by Friedman's test that converts scores to rankings, whereby results with the same rank get the so-called bound or common rank. This test is used when there are a number of repeated experimental situations or repeated measurements. Although the test primarily serves to verify the hypothesis, here it will be used to rank the data according to the relevance.

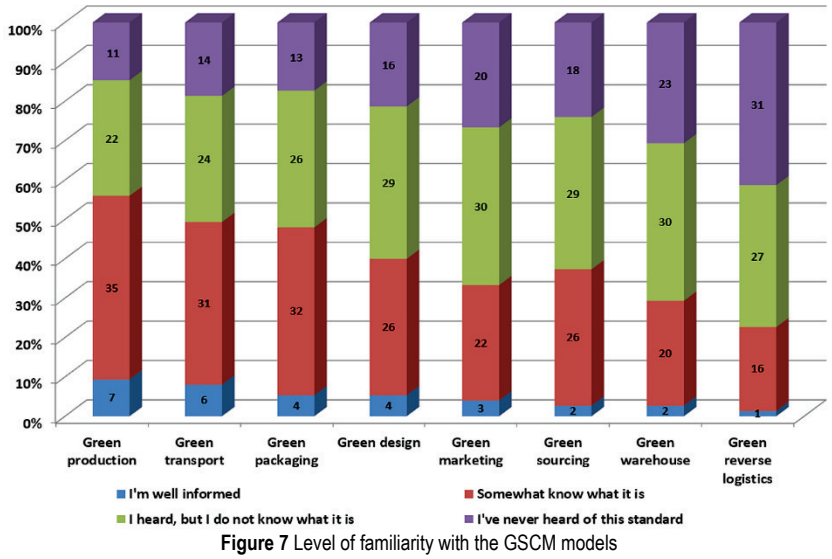

Figure 7 Level of familiarity with the GSCM models

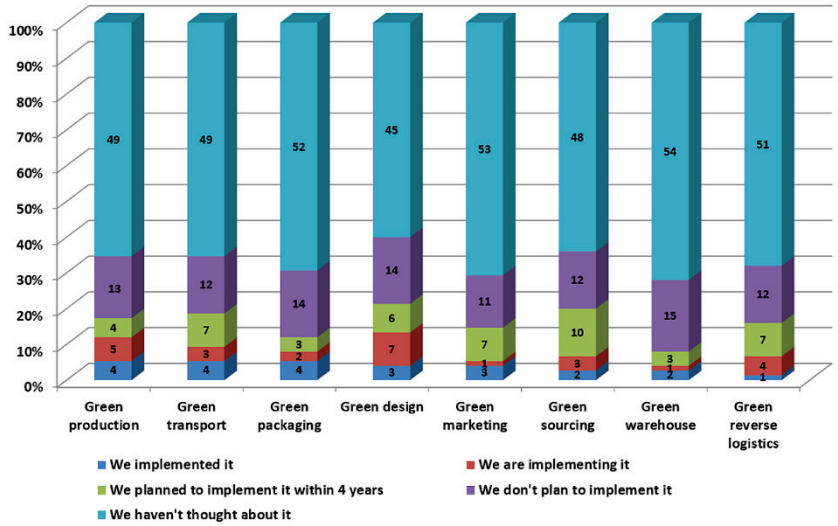

Figure 8 Level of implementation of the GSCM models

Table 1 The most significant models of GSCM

Model within the GSCM concept	Average rank	Arithmetic mean	Standard deviation
Green production	6.09	6.09	2.27
Green sourcing	5.35	5.35	2.39
Green transport	4.79	4.79	1.83
Green packaging	4.57	4.57	1.83
Green design	4.23	4.23	2.24
Green warehouse	4.09	4.09	1.97
Green marketing	4.00	4.00	2.49
Green reverse logistics	2.88	2.88	1.84

Tab. 1 shows the most significant GSCM models in Croatian companies. From Tab. 1, it is apparent that the companies consider green production and green sourcing as the models of GSCM which are of greatest significance for the process of implementation. On the other hand, green marketing and green reverse logistics are the models of GSCM that have the lowest impact on the process of implementation. These results can be used to help companies decide which model of GSCM is better to use or implement in their company.

4.2 Drivers for the Implementation of GSCM

Based on literature review, Holt's doctoral thesis [10], GSCM drivers can be divided into eight categories:

- Legislative regulations imply the need of companies to comply with the Croatian environmental regulations, the EU's environmental regulations and the forthcoming regulations. It should be noted that the above mentioned EU directives and EPAs already define how companies must adapt to them. In the opinion of the authors of this paper and in the opinion of Holt [9], this is one of the most important factors for the implementation of GSCM.
- Social pressure is a term which defines the pressure of society on how the enterprise or organization should behave. Many companies have to comply with safety and health standards (OHSAS18001, ISO14001) to be able to deal with specific supply chain participants. Likewise, it is very important for marketing to maintain a certain image of an environmentally conscious company or organization, so they do not lose existing customers, as well as to gain future customers or users.
- Professional and industrial associations (bodies) represent the pressure of trade unions, trade associations and others to implement GSCM within the company.
- Financial factors also greatly encourage the implementation of GSCM into companies. Many companies have achieved significant savings by implementation of some elements of GSCM into the enterprise. Toyota has saved $ 3.6 million in 1990 by developing standard packaging for suppliers to reuse or recycle the packaging [10]. Public Service Electric and Gas Company has saved more than $ 2 million by reducing the number of suppliers from 270 to 9 [2]. From financial factors, the biggest emphasis is on reducing operating costs within a company.
- Supply chain factors imply pressure and initiatives by upstream and downstream supply chains.
- Internal factors are drivers that occur within the company itself. They can come from a director or an employee and can also be part of an organization's corporate culture. This is primarily the case if business operates in an environment where employees live, and thus want to improve the quality of their lives.
- Competitiveness factors are largely linked to financial factors. These factors want to create new profits on the market and to achieve results better than competitors or at least keep up with the competition.
- Risk factors imply drivers that reduce the risk of potential pollution related to company products or services and disposal of products at the end of their life cycle.

When the GSCM drivers are analyzed, as shown in Tab. 2, it can be seen that within seven most significant drivers, the most significant factors are the competitive factors. This implies that there is a desire to compete better, keep up with competition, and to create new profits. Adapting businesses

to the existing EU environmental regulations and upcoming environmental regulations is a legislative regulation that is within the seven most significant drivers.

By analyzing seven least significant drivers, we can see that social factors are prevailing (to maintain or present an image of an environmentally or socially responsible company/internationally societal public expectation/societal public expectation in Croatia). Employee pressure (internal factor) and union pressure (professional and industrial associations/bodies) are the drivers with the least impact on the introduction of GSCM. From the above-mentioned, it can be concluded that social factors and pressure (from employees, trade unions, shareholders, etc.) are drivers with the least impact on the introduction of GSCM into the enterprise.

Table 2 Rank of the drivers in the implementation of GSCM

Drivers in the implementation of GSCM		Average rank	Arithmetic mean	Standard deviation
Competitiveness factors	In order to perform better than our competitors	15.75	4.12	1.38
Competitiveness factors	In order to keep up with competitors	15.66	4.17	1.23
Legislative regulations	To comply with current EU environmental legislation	15.36	4.05	1.42
Internal factors	The CEO is committed to environmental improvement	14.81	4.07	1.29
Competitiveness factors	New profit opportunities in the market	14.59	3.96	1.37
Legislative regulations	In order to pre-empt possible legislation in the future	14.44	3.89	1.47
Financial factors	To achieve savings in operating costs	14.25	3.96	1.38
Risk	In order to reduce health and safety risks associated with our goods, services and operational practices	14.21	3.96	1.32
Legislative regulations	To comply with current Croatian government environmental regulations	13.87	3.87	1.38
Internal factors	Environmental responsibility is part of the organizational culture of our company	13.57	3.89	1.29
Risk	In order to reduce health and safety risks associated with the disposal of our products or materials we use at the end of their life cycle	13.37	3.87	1.33
Supply chain factors	Pressure or encouragement from businesses you supply with goods and services	12.60	3.72	1.36
Professional and industrial associations (bodies)	Pressure from professional bodies, trade associations	11.85	3.65	1.29
Social pressure	Pressure from green action groups (Greenpeace)	11.51	3.56	1.35
Social pressure	Public opinion in local area	11.36	3.55	1.37
Risk	In order to reduce the public's perceived risk associated with our company	11.35	3.57	1.31
Supply chain factors	Pressure from individual consumers	11.30	3.61	1.22
Social pressure	To maintain or present an image of an environmentally or socially responsible company	11.26	3.51	1.40
Financial factors	Pressure from shareholders and investors	11.10	3.41	1.47
Social pressure	Internationally societal public expectation	11.07	3.49	1.35
Financial factors	Pressure from insurance industry	10.54	3.37	1.41
Social pressure	Societal public expectation in Croatia	10.47	3.43	1.29
Internal factors	Pressure from employees	8.09	3.15	1.16
Professional and industrial associations (bodies)	Pressure from the trade union	7.61	2.99	1.22

Tab. 3 shows the factor analysis of the drivers in the implementation of GSCM. The factor analysis was performed in order to group and explain numerous drivers of the GSCM implementation by minimal number of factors. The criterion for acceptance of the factor is when factor loading has a value of more than 0.70.

From the Tab. 2, we can see that factor 1 describes all internal GSCM drivers, thus this factor can be called the internal factor of the GSCM implementation. In addition to internal drivers, factor 1 also describes other risk based drivers, but these drivers can easily be classified as internal, since they are closely related to the organization of the company. A driver "to maintain or present an image of an environmentally or socially responsible company" is equally described by factor 1 and factor 2 and will be placed under factor 2.

Factor 2 describes the drivers that are linked to legislative regulations and social pressure. As such, it can be called the factor of legal regulation and social pressure.

Factor 3 can be defined as a financial factor as it describes two financial drivers, one risk related driver and one driver related to professional and industrial associations (bodies). This is especially true when one takes into account that the pressure of the trade union may be placed under financial drivers because it affects the company's finances.

Table 3 Factor analysis of the drivers in the implementation of GSCM

Drivers in the implementation of GSCM		Factor 1	Factor 2	Factor 3	Factor 4
Legislative regulations	To comply with current Croatian government environmental regulations	0.1682	0.7544	-0.0132	0.3394
	To comply with current EU environmental legislation	0.1810	0.7439	0.0675	0.4348
	In order to pre-empt possible legislation in the future	0.1728	0.6981	0.0195	0.3109
Social pressure	Public opinion in local area	0.2427	0.7835	0.2950	0.1546
	Societal public expectation in Croatia	0.2603	0.7787	0.2916	0.2054
	Internationally societal public expectation	0.4413	0.7201	0.2590	-0.0888
	Pressure from green action groups (Greenpeace)	0.1846	0.6519	0.2324	0.0866
	To maintain or present an image of an environmentally or socially responsible company	0.4422	0.4370	0.1975	0.3953
Professional and industrial associations (bodies)	Pressure from professional bodies, trade associations	0.2943	0.3849	0.3715	0.5834
	Pressure from the trade union	0.1481	0.4274	0.6545	0.2742
Financial factors	Pressure from shareholders and investors	0.2842	0.1144	0.7978	0.2411
	Pressure from insurance industry	0.2404	0.1478	0.8425	0.2138
	To achieve savings in operating costs	0.5475	0.1301	0.2241	0.6121
Supply chain factors	Pressure or encouragement from businesses you supply with goods and services	0.3787	0.0867	0.4966	0.5622
	Pressure from individual consumers	0.5330	0.2364	0.3950	0.5037
Internal factors	Pressure from employees	0.5967	0.3641	0.2278	0.2434
	The CEO is committed to environmental improvement	0.7259	0.2423	0.2863	0.1994
	Environmental responsibility is part of the organizational culture of our company	0.7105	0.3715	0.3066	0.2578
Competitiveness factors	New profit opportunities in the market	0.1856	0.4214	0.2360	0.7690
	In order to keep up with competitors	0.3649	0.1878	0.4101	0.6748
	In order to perform better than our competitors	0.4832	0.2069	0.2780	0.6710
Risk	In order to reduce health and safety risks associated with our goods, services and operational practices	0.7852	0.2730	0.1496	0.2992
	In order to reduce health and safety risks associated with the disposal of our products or materials we use at the end of their life cycle	0.7671	0.2201	0.2813	0.3189
	In order to reduce the public's perceived risk associated with our company	0.4065	0.2950	0.5699	0.3642

Finally, factor 4 can be called competitiveness factor because it describes all of them. In addition to the competitiveness drivers, it describes the driver "to achieve savings in operating costs", which, of course, leads to an increase in company competencies. Factor 4 also describes two drivers associated with the pressure of professional and trade associations (bodies), and the one driver associated with the pressure or initiatives from the companies that are supplying goods or services.

Although some of the drivers in the mentioned category do not belong under the same factors, such category will not make significant mistakes and it can freely be said that these four factors can replace the above mentioned eight categories of the GSCM implementation drivers. Factor 2 describes two categories, so it will be divided into two categories. In accordance with the above-mentioned, Tab. 4 shows a new actuator category according to the factor analysis results, by which the number of categories decreases from eight to five.

4.3 Barriers for the Implementation of GSCM

Based on the literature review, Holt [10], Ageron et al. [13], and Khiewnavawong [14], the barriers to GSCM implementation are divided into six categories:

- Supply Chain participants (suppliers and customers) category includes barriers related to the upstream and downstream part of the supply chain, i.e. buyers and suppliers.
- Economic factors related to the investments in "green" projects and prices of "green" products.
- Perception implies the perception of environmental thinking within a company. Often, employees have a negative attitude towards environmental initiatives, which at the start can condemn projects and bring downfall.
- Motivation is a very important category when implementing GSCM into a company because it is very important in some phases to motivate employees. This includes barriers whose existence affects employee motivation and their desire, or resistance to change.

- Implementation implies barriers that may make it difficult to implement GSCM within the company. These can be legislative regulations that change, the change of technology, etc.
- Resource limitation includes constraints that can be associated with human resource constraints, government support, and the lack of material resources (raw materials, technology and equipment).

Table 4 The new classification of the drivers in the implementation of GSCM

Legislative regulations	To comply with current Croatian government environmental regulations
	To comply with current EU environmental legislation
	In order to pre-empt possible legislation in the future
Social pressure	Public opinion in local area
	Societal public expectation in Croatia
	Internationally societal public expectation
	Pressure from green action groups (Greenpeace)
	To maintain or present an image of an environmentally or socially responsible company
Internal factors	Pressure from individual consumers
	Pressure from employees
	The CEO is committed to environmental improvement
	Environmental responsibility is part of the organizational culture of our company
	In order to reduce health and safety risks associated with our goods, services and operational practices
	In order to reduce health and safety risks associated with the disposal of our products or materials we use at the end of their life cycle
Financial factors	Pressure from the trade union
	Pressure from shareholders and investors
	Pressure from insurance industry
	In order to reduce the public's perceived risk associated with our company
Competitiveness factors	Pressure from professional bodies, trade associations
	To achieve savings in operating costs
	Pressure or encouragement from businesses you supply with goods and services
	New profit opportunities in the market
	In order to keep up with competitors
	In order to perform better than our competitors

Tab. 5 shows the rank of barriers in the implementation of GSCM in Croatian companies. From Tab. 5 we can see that among seven barriers with the strongest influence on the GSCM implementation, four of them are connected with the economics factors. Those factors are related to green initiatives and products (high operating cost, high investment cost, higher cost of raw material, higher cost of products). Other three are connected with supply chain participants, but are also related to the costs regarding the participants of the supply chain. The last barrier among the seven with most influence is the one connected with the implementation that the laws/regulations keep changing and it is hard to find the right information.

On the other hand, seven barriers with the lowest influence on the implementation of GCSM are connected with the implementation that it is hard to follow technology which is changing all the time and with the problem of measuring the results of green project. Here are also barriers related to the resources limitation (poor quality of environmentally friendly resources), supply chain participants (size of the company), perception (company believes that green initiatives are not widely accepted or used in an industrial sector or geographic area) and motivation (that there are some powerful individuals in the company that resist the change).

Factor analysis was also conducted for the barriers for GSCM implementation, but the results could not be interpreted due to low degree of parsimony. Hence, the barriers should be interpreted individually.

Table 5 Rank of the barriers in the implementation of GSCM

Barriers in the implementation of GSCM		Average rank	Arithmetic mean	Standard deviation
Economic factors	They require high operating costs	25.68	4.32	1.32
Supply chain participants	Suppliers/customers do not have budget for investing	25.21	4.29	1.31
Economic factors	Green projects require high investment costs in building or changing facility and equipment	25.02	4.25	1.37
Economic factors	Costs of raw material for green initiatives are higher than non-green	24.17	4.19	1.37
Supply chain participants	Suppliers/customers are concerned about the price that might be higher due to green	23.31	4.15	1.33
Economic factors	Green's higher price cannot compete with competitor's lower price	23.15	4.13	1.34

Table 5 Rank of the barriers in the implementation of GSCM (continuation)

Barriers in the implementation of GSCM		Average rank	Arithmetic mean	Standard deviation
Implementation	The laws/regulations keep changing and it is hard to find the right information	22.24	4.12	1.28
Supply chain participants	Suppliers/customers do not have information, resources and expertise to implement	22.17	3.99	1.44
Economic factors	Fear that the benefits of implementing environmental thinking will not return their investment	21.66	3.91	1.42
Resources limitation	Lack of support from government	21.23	3.97	1.41
Resources limitation	Limitation of technical knowledge	20.67	3.87	1.39
Resources limitation	Lack of process standardization	20.27	3.89	1.36
Resources limitation	Lack of knowledge to implement green	20.19	3.83	1.39
Resources limitation	Lack of human resources that specialize in green	20.17	3.79	1.45
Motivation	The company regards new investment in redesigning the product to be green as fruitless	19.98	3.77	1.45
Supply chain participants	Size and complexity of the supply chain	19.55	3.69	1.49
Perception	Top management does not believe in green	19.51	3.56	1.60
Perception	The company believes that green is complicated and unattainable	19.09	3.69	1.43
Implementation	The company does not comply with regulations or permits	19.01	3.69	1.49
Supply chain participants	Lack of environmental standards and audit programs at the suppliers/customers	19.01	3.61	1.53
Perception	The company does not feel responsible for the environmental issues	18.67	3.63	1.44
Supply chain participants	Suppliers/customers do want to cooperate in green with us	18.65	3.67	1.43
Perception	The company is uncertain about the environmental benefits of the green initiatives	18.53	3.60	1.50
Supply chain participants	Human skills of the suppliers/customers	18.04	3.67	1.36
Perception	The company believes that green is not important or relevant to the business	18.00	3.61	1.42
Economic factors	There is not enough market-based incentives to invest in green	17.95	3.64	1.32
Motivation	Focal company on previous experiences on sustainability	17.85	3.63	1.41
Resources limitation	Lack of environmentally friendly resources	17.81	3.67	1.41
Motivation	Lack of support and commitment from top management	17.56	3.45	1.48
Implementation	Lack of communication among the departments involved	17.33	3.51	1.46
Supply chain participants	Suppliers/customers are hesitant in the performance on green products/process	17.32	3.51	1.42
Motivation	Green is not a challenging technological innovation opportunity for our company	16.79	3.51	1.36
Motivation	There are some powerful individuals in the company that resist change	16.73	3.35	1.58
Perception	The company believes that green initiatives are not widely accepted or used in an industrial sector or geographic area	16.40	3.45	1.40
Supply chain participants	Suppliers/customers company size	16.26	3.47	1.40
Implementation	It is hard to follow current technology because it changes all the time	15.89	3.52	1.33
Resources limitation	Poor quality of environmentally friendly resources	15.29	3.36	1.44
Implementation	It is hard to measure/assess results of green projects	14.66	3.31	1.38

5 CONCLUSION

As mentioned earlier in the paper, some of the questions are taken from already conducted surveys in the EU and the USA. Drivers of implementation of GSCM can be compared with the survey conducted by Holt in the British companies [10]. It can be concluded that there are certain similarities and differences between the drivers in the UK and Croatia. In both countries, among the most significant drivers are the drivers associated with legislative regulations category. The difference is in the fact that companies in the UK are considering the risk factor more, while Croatian companies are considering competitiveness factors more. Also, among the most significant drivers in both cases there is an internal

factor: in the British companies that is "environmental responsibility is part of the organizational culture of our company", and in Croatian companies that is "the CEO is committed to environmental improvement".

As a conclusion it can be said that companies in the UK look at GSCM as a concept that, apart from compliance with legislative regulations, can reduce the impact and risk to the environment and health of employees. On the other hand, Croatian companies also look at GSCM as a concept that allows easier compliance with legislative regulations, but it also helps to create new profits and keep pace or even be better than competition. Generally speaking, companies in the UK, when it comes to GSCM drivers, have a better developed ecological awareness.

When we look at least significant drivers, there is also a certain similarity between the results of these two surveys. In the UK and Croatia, amongst the least significant drivers are as follows: "pressure from employees" (as an internal factor), "pressure from shareholders and investors", and "pressure from insurance industry" (as a financial factor). The difference is that supply chain factors prevail in the UK, while social pressures prevail in Croatia. Furthermore, it can be concluded that neither in the UK nor in Croatia the pressure within the supply chain and social pressure does not contribute to the implementation of GSCM into the enterprise.

Research questions for the barriers in the implementation of GSCM were taken from three different surveys: Ageron et al. [13] conducted in France, Holt [10] research conducted in the UK, Khiewnavawong [14] research conducted in the electrical and electronic industry in the USA. Because of that, the data cannot be compared unequivocally, but will be compared shortly. When looking at the results of the most significant barriers in Croatia (Tab. 5), it can be seen that four of seven most significant barriers belong into the economic factors category. There are two barriers associated with the supply chain factors, but are also related to the price. The last barrier is related to the implementation of GSCM. In the surveys conducted in other countries [10, 13, 14], most significant barriers are the ones connected with the economic factors such as the higher price of green products, greater cost of the raw materials, lack of human resources, higher operating costs, and more. Therefore, it can be concluded that there is no significant difference in the results between the compared surveys.

On the other hand, when looking at the least significant barriers, the same conclusion is reached. Although certain barriers do not coincide, barriers with the least impact are those that are related to the motivation, perception and implementation of GSCM in the enterprise. Most often, however, there are barriers related to the size of the company, difficulties in following new technology, and measuring the results of green projects. Generally, regarding the barriers, there are not so many differences in answers comparing Croatian companies and companies from other countries.

Results of this paper can help companies in implementing GSCM into their organizations so as to guide them through the process of implementation according to the most and less significant drivers and barriers. This is especially important if we take into consideration that the companies are not familiar with the GSCM concept and its models.

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Original scientific paper

THE VIBRATION OF NANOBEAM RESTING ON ELASTIC FOUNDATION USING MODIFIED COUPLE STRESS THEORY

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Abstract: In this paper, the vibration of nanobeams resting on the Winkler foundation is proposed using the modified couple stress theory. Hamilton's principle is utilized to construct the governing equations. The size effect of the nanobeam cannot be captured by using classical Euler-Bernoulli beam theory, but the modified couple stress theory model can capture it because it includes material length scale parameter that a newly developed model has. Once the material length scale parameter is assumed to be zero, the classical Euler-Bernoulli beam theory equation is obtained. Multiple scale method is employed to obtain the result. Simply supported boundary condition is used to study natural frequencies. The influence of material length scale parameter and the Winkler elastic foundation parameter on the fundamental frequencies of the nanobeam is investigated and tabulated. Also, in the present study, Poisson's ratio is taken as constant. Nanobeam resting on the Winkler foundation which is simply supported is analyzed to illustrate the size effects on the free vibration. Numerical results for the simply supported nanobeam indicate that the first fundamental frequency calculated by the presented model is higher than the classical one. Moreover, it is obtained that the size influence is more substantial for higher vibration modes. The results indicate that the significant importance of the size influences the analysis of nanobeams. The vibration of nanobeam exhibits a hardening spring behavior, and the newly developed models are the beams stiffer than according to the classical beam theory. Modified couple stress theory tends to be more helpful in describing the size-dependent mechanical properties of nanoelectromechanical systems (NEMS).

Keywords: nanobeam; modified couple-stress theory; perturbation methods; Winkler foundation

1 INTRODUCTION

In recent years, research on nanostructures, which are used as a fundamental part of a large number of micro and nanoelectromechanical systems (MEMS and NEMS), has received great interest from researchers. Standard MEMS and NEMS consist of conventional silicon-based materials, metal thin beams, functional graded materials, or polymers. The dynamic and mechanical behavior of nanostructures has been particularly interesting for scientists. The method of the development of non-classical continuity theory is substantial to model the nano- and micro-structures in the aspects of dynamic and static properties, because it is time-consuming and difficult to conduct experiments at the nanoscale. The inclusion of material length parameters in the equations of motion for defining size effect is possible with non-classical continuum theories for analyzing nanostructures [1].

Nowadays, modified couple stress theory (MCST), which is a size-dependent continuum theory, has been an attractive research subject for scientists and engineers. Mechanical properties of nanostructures in terms of linear and nonlinear are discussed by introducing the size effect in motion equations. Park and Gao [2] initially applied the modified couple stress theory into the study to examine the microcantilever Euler-Bernoulli beam under the influence of a point load in static deformation.

Recently, couple stress effect is being used by scientists to investigate the size influence of nanostructures. In the literature survey, mechanical characteristics of nanobeams are investigated using various beam models on the basis of Euler-Bernoulli, Timoshenko and Reddy beam theories to analyze the dimensional effect. Double-walled boron nitride nanotubes (DWBNNTs) conveying fluid embedded in a viscoelastic foundation is modeled to investigate the geometric nonlinearity effect, the size effect, transverse shear deformation effect, and rotary inertia effect [3]. In their work, they have considered the viscoelastic medium spring and damping constants, the small-scale coefficient and instability behaviors of DWBNNT and fluid velocity on vibration. The results of their studies indicated that the damping constant has a substantial influence on the critical flow velocity and resonant frequencies. Double-walled carbon nanotubes (DWCNTs) that convey fluid are examined with the aid of the modified couple stress theory to analyze the vibration and instability characteristics. The results of their studies showed that the effect of length scale parameter performs a significant role in the fluid conveying DWCNNTs frequency and critical flow velocity. Şimşek and Reddy [5, 6] performed a different beam theory on the base of the modified couple stress theory to analyze the free vibration and buckling of functionally graded microbeams. Simsek [7] focused on the static bending of microbeams in large amplitude and free vibration of microbeams on the nonlinear elastic medium by employing Euler-Bernoulli beam theory and modified couple stress theory. His results indicated that the increment of the dimensionless scale parameter decreases the nonlinear frequency ratio. Moreover, nonlinear foundation parameter has an opposite influence on the nonlinear frequency related to Winkler and Pasternak parameters. Barooti and Ghadiri [8] studied the critical speed and free vibration analysis of spinning 3D SWCNTs rested on an elastic medium considering the modified couple stress theory. They have concluded that material length scale parameter and the angular velocity have an important effect on the rotating SWCNTs fundamental frequencies.

Eringen [9] has developed a size-dependent theory titled as a nonlocal elasticity theory. According to this theory, the stress state at a given reference point is a function of the strain field at every point in the body.

Hence, the nonlocal continuum mechanics theory includes information about the internal length scale and the long-range forces between atoms are inserted into the structural equations just as the parameter of material length

scale. Peddieson et al. [10] have been first to apply the theory of nonlocal Euler–Bernoulli beam to nano- and micro-structures. In that study, Peddieson et al. [10] studied the cantilever beam by applying the newly developed theory called a nonlocal Euler–Bernoulli beam. For nanomaterials, the theory of non-local elasticity was suggested to reveal the scale effects. Eringen's nonlocal differential constitutive relation has been applied by Soltani et al. [11] to analyze the nonlinear vibration characteristics of the fluid-conveying CNTs. Damping and elastic medium effect on critical flow velocity and resonant frequency have been discussed by Soltani et a. [11]. With the help of the nonlocal elasticity model, effect of viscoelastic foundation on the cantilever carbon nanotubes to obtain the structural stability [12], nanobeam rested on an elastic medium to analyze the vibration characteristics [13] and nanobeam rested on Pasternak type elastic medium [14], fluid-conveying non-uniform CNTs embedded in viscoelastic medium to analyze the vibration responses [15], nanotube embedded in viscous matrix to analyze the nonlinear free vibrations [16], DWCNTs that convey fluid embedded in viscoelastic medium to analyze the thermal-mechanical vibration and instabilities [17] have been investigated by researchers.

Theory of Eringen's nonlocal elasticity is one of the best and well-known theories by all the researchers who studied the nonlocal continuum mechanics. That theory includes the effect of small scale with enough precision in micro/nanoscale equipment. In addition to this theory, the modified couple stress theory is also the valuable theory. The researches indicated that the modified couple stress theory is compatible with the experimental results of Eringen's nonlocal elasticity and classical theories [9]. Therefore, this is the reason why the theory of modified couple stress theory has been introduced in governing equations in the present study.

All of the useful studies mentioned in the literature review employed the theory of Eringen's nonlocal elasticity to microbeam and nanobeam. Moreover, most of the studies examine the vibration characteristics of nanobeam resting on an elastic medium on the basis of Eringen's nonlocal elasticity theory. In the present study, nanobeam resting on an elastic medium is examined to analyze the vibration characteristics using the modified couple stress theory. The length scale parameter effect and linear foundation stiffness coefficients on the linear frequency are analyzed. In addition, considerable numerical data is presented in tabulated form for various values of the parameters; hence in the future, these results may be used as a reference.

2 SIZE DEPENDENT NANOBEAM RESTING ON AN ELASTIC FOUNDATION EQUATIONS

2.1 The Modified Couple Stress Theory

The scope of modified couple stress theory was firstly presented by Yang et al. [18]. Based on this theory, the strain energy is a function of both the rotation gradient tensor and strain tensor. Moreover, it consists of two Láme parameters and one length scale parameter. When we look at this theory, the strain energy follows as:

$$U = \frac{1}{2}\iiint_V (\sigma_{ij}\varepsilon_{ij} + m_{ij}\chi_{ij})\mathrm{d}V \tag{1}$$

where σ_{ij} is the stress tensor, ε_{ij} is the strain tensor, m_{ij} is the higher order stress tensor and χ_{ij} is symmetric rotation gradient tensor. These tensors are given as

$$\sigma_{ij} = \lambda\varepsilon_{kk}\delta_{ij} + 2\mu\varepsilon_{ij} \tag{2}$$

$$\varepsilon_{ij} = \frac{1}{2}\left(u_{i,j} + u_{j,i}\right) \tag{3}$$

$$m_{ij} = 2\mu l^2\chi_{ij} \tag{4}$$

$$\chi_{ij} = \frac{1}{2}\left(\theta_{i,j} + \theta_{j,i}\right) \tag{5}$$

where u_i is the displacement vector and δ_{ij} is the Kronecker delta. l is the material length scale parameter and θ_i is the rotation vector that can be given as

$$\theta_i = \frac{1}{2}e_{ijk}u_{k,j} \tag{6}$$

where e_{ijk} is the permutation symbol. λ and μ are the Láme's constants that are given as

$$\lambda = \frac{E\nu}{(1+\nu)(1-2\nu)},\ \mu = \frac{E}{2(1+\nu)} \tag{7}$$

where ν, μ and E are Poisson's ratio, shear modulus and Young's modulus, respectively.

2.2 Governing Equations and Boundary Conditions

Hamilton's principle and the modified couple stress theory that allow to derive the equations of motion and boundary conditions to construct the governing equations are derived for nanobeam, for the Euler-Bernoulli beam model, resting on the elastic medium. Fig. 1 schematically represents a simply supported nanobeam.

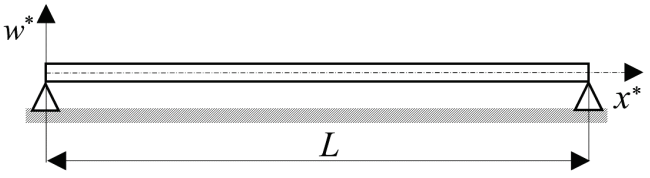

Figure 1 Simply supported beam

For the system shown in Fig. 1, w^* is the beam transverse displacement between supports and L is the length of the beam. Lagrange equation is given in Eq. (8), ρA is the mass per unit length, t^* is the time, N^* is the axial force, EI is flexural rigidity and EA is longitudinal rigidity.

$$\pounds = \frac{1}{2}\int_0^L \rho A\left(\frac{\partial w^*}{\partial t^*}\right)^2 \mathrm{d}x^* - \frac{1}{2}\int_0^L EI\left(\frac{\partial^2 w^*}{\partial x^{*2}}\right)^2 \mathrm{d}x^* - \\ -\frac{1}{2}\frac{E}{2(1+\nu)}Al^2\int_0^L\left(\frac{\partial^2 w^*}{\partial x^{*2}}\right)^2 \mathrm{d}x^* - \\ -\frac{1}{2}\int_0^L N^*\left(\frac{\partial w^*}{\partial x^*}\right)^2 \mathrm{d}x^* - \frac{1}{2}\int_0^L kw^{*2}\mathrm{d}x^* \tag{8}$$

The governing equation of motion of nanobeam considering the dimensional form is acquired with the help of Hamilton's principle and by implementing the necessary algebra:

$$\left(EI + \frac{E}{2(1+\nu)}Al^2\right)\frac{\partial^4 w^*}{\partial x^{*4}} + \rho A\frac{\partial^2 w^*}{\partial t^{*2}} + kw^* = \\ = \frac{EA}{2L}\left[\int_0^L\left(\frac{\partial w^*}{\partial x^*}\right)^2 \mathrm{d}x^*\right]\frac{\partial^2 w^*}{\partial x^{*2}} \tag{9}$$

The term $\mu Al^2(\partial^4 w^*/\partial x^{*4})$ comes from modified couple stress theory. Nanobeam nanostructure has been introduced into the equation by considering the material length scale parameter *l*. The corresponding boundary conditions at the ends of the beam ($x^* = 0$ and $x^* = L$) are given as:

Simple-Simple Case:

$$w^*(0) = 0, \quad w^*(L) = 0 \\ w^{*\prime\prime}(0) = 0, \quad w^{*\prime\prime}(L) = 0 \tag{10}$$

the dimensionless form by considering the Eqs. (9) and (10) can be described as:

$$\overline{x} = \frac{x}{L},\ \overline{w} = \frac{w}{L},\ \overline{t} = \frac{t}{L^2}\sqrt{\frac{EI}{\rho A}}, \\ \xi = \frac{h}{l},\ \eta = \frac{6}{(1+\nu)\xi^2},\ \kappa = \frac{kL^4}{EI} \tag{11}$$

$$(1+\eta)\frac{\partial^4 \overline{w}}{\partial \overline{x}^4} + \frac{\partial^2 \overline{w}}{\partial \overline{t}^2} + \kappa\overline{w} = \frac{1}{2}\left[\int_0^1\left(\frac{\partial \overline{w}}{\partial \overline{x}}\right)^2 \mathrm{d}\overline{x}\right]\frac{\partial^2 \overline{w}}{\partial \overline{x}^2} \tag{12}$$

The dimensionless form of boundary conditions at the end of beam is as follows:

Simple-Simple Case:

$$\overline{w}(0) = 0, \quad \overline{w}(1) = 0 \\ \overline{w}''(0) = 0, \quad \overline{w}''(1) = 0 \tag{13}$$

3 SOLUTIONS USING A PERTURBATION TECHNIQUE

In this part of the study, an analytical solution will be approximately obtained with the help of the multiple scale methods having an important perturbation technique. According to the following expansion,

$$\overline{w}(x, t; \varepsilon) = \overline{w}_0(x, T_0; T_1) + \varepsilon\overline{w}_1(x, T_0; T_1) \tag{14}$$

where $T_0 = T$, $T_1 = \varepsilon T$ and $\varepsilon << 1$ [19-20]. $\overline{\mu} = \varepsilon\mu$, $\overline{F} = \varepsilon\sqrt{\varepsilon}F$ the transformation is implemented for the forcing and damping terms on the basis of the multiple scale method [19, 20], respectively. Introducing,

$$\frac{\partial}{\partial t} = D_0 + \varepsilon D_1,\ \frac{\partial^2}{\partial t^2} = D_0^2 + 2\varepsilon D_0 D_1 \tag{15}$$

where $D_n = \partial/\partial T_n$. After making the necessary expansion, the different order of motion equations and boundary conditions are given in the following form:

Order (1):

$$(1+\eta)\overline{w}_0^{iv} + D_0^2\overline{w}_0 - v_p^2\overline{w}_0 = 0 \tag{16}$$

Order (ε):

$$(1+\eta)\overline{w}_1^{iv} + D_0^2\overline{w}_1 - v_p^2\overline{w}_1 = -2D_0D_1\overline{w}_0 + \\ + \frac{1}{2}\left[\int_0^1 \overline{w}_0''^2\mathrm{d}x\right]\overline{w}_0'' + F\cos\Omega t - 2\mu D_0\overline{w}_0 \tag{17}$$

Fundamental frequency which possesses first order of expansion can be obtained.

3.1 Linear Problem

Linear problem is frequently represented by the first order of equation given in Eq. (16). The problem solution is given in the complex form as:

$$\overline{w}_0(x, T_0, T_1) = A(T_1)\mathrm{e}^{i\omega T_0}Y(x) + \overline{A}(T_1)\mathrm{e}^{-i\omega T_0}\overline{Y}(x) \tag{18}$$

A is the complex amplitude. Substituting Eq. (18) into Eq. (17), the following can be obtained:

$$(1+\eta)Y^{iv}(x) - \frac{\omega^2}{\alpha}Y(x) = 0 \tag{19}$$

The solution of *Y*(*x*) can be obtained as follows:

$$Y(x) = c_1\mathrm{e}^{i\beta_1 x} + c_2\mathrm{e}^{i\beta_2 x} + c_3\mathrm{e}^{i\beta_3 x} + c_4\mathrm{e}^{i\beta_4 x} \tag{20}$$

Since the boundary conditions are considered, the frequency equations are obtained.

4 NUMERICAL RESULTS

All the obtained fundamental frequency values in this study consider the modified couple stress theory and Euler-Bernoulli beam theory. Influence of the dimensionless material length scale parameter h/l is indicated by the ζ symbol. Since it is working in dimensionless form, the dimensionless Winkler spring constant (κ) and dimensionless material length scale parameter (ζ) are sufficient to calculate the results. In Tab. 1, the fundamental frequencies with different length scale parameter, the Winkler spring constant and simply supported boundary are given. In this table, Poisson's ratio is taken as $\nu = 0.38$, and the dimensionless material length scale parameter with h/l=1, 2, 3, 4 and 5 and the dimensionless Winkler foundation parameter with κ = 0,100 and 500, respectively. It is obvious from the table that the natural frequencies increase once the dimensionless Winkler foundation parameter (κ) increases. This is because increasing the Winkler foundation parameters increases the stiffness of the beam. It is well known that the fundamental frequencies of a system generally increase the increment of the foundation stiffness. On the other hand, Tab. 1 reveals that increment in the scale parameter causes the decrease in the fundamental frequencies. It is known that the influence of the small scale has an effect on the nanotube mechanical behaviors.

Table 1 The first five frequencies for different κ and ξ values and $\nu = 0.38$ for Simple-Simple support condition

$\kappa = 0$					
ξ	1	2	3	4	5
ω_1	22.8238	14.2579	12.0194	11.1301	10.6934
ω_2	91.2953	57.0317	48.0777	44.5204	42.7738
ω_3	205.414	128.321	108.175	100.171	96.241
ω_4	365.181	228.127	192.311	178.081	171.095
ω_5	570.596	356.448	300.486	278.252	267.336
$\kappa = 100$					
ξ	1	2	3	4	5
ω_1	24.9184	17.4152	15.6354	14.9626	14.6407
ω_2	91.8413	57.9018	49.1067	45.6296	43.9272
ω_3	205.658	128.71	108.636	100.669	96.7592
ω_4	365.318	228.346	192.571	178.362	171.387
ω_5	570.683	356.588	300.652	278.432	267.523
$\kappa = 500$					
ξ	1	2	3	4	5
ω_1	31.9519	26.5196	25.3863	24.9776	24.7861
ω_2	93.9938	61.2586	53.0233	49.8203	48.2659
ω_3	206.628	130.255	110.462	102.636	98.8045
ω_4	365.865	229.22	193.606	179.48	172.55
ω_5	571.034	357.149	301.317	279.149	268.27

5 CONCLUDING REMARKS

In this study, modified couple stress theory is proposed for the nanobeam which is on an elastic foundation. The simply supported nanobeam has been compared with the Euler-Bernoulli beam type as a benchmark for beam analysis study. Results for natural frequencies are obtained with multiple scale method. The influences of non-dimensional material length scale parameter (ξ), non-dimensional Winkler foundation parameter (κ) and simply supported boundary condition are tabulated. It was found that:

- Non-dimensional material length scale parameter (ξ) effect plays a substantial role in the fundamental frequency of the nanobeam. The natural frequency is declined with the increment of dimensionless material length scale parameter. This effect leads to softening the nanobeam.
- The non-dimensional Winkler spring constant (κ) is increasing with the increase of fundamental frequency of the nanobeam. This effect increases the system stiffness.
- All values of the numerical results show that the fundamental frequency of the nanobeam decreases with increment of the non-dimensional material length scale parameters and increases with increment of non-dimensional Winkler foundation parameters.

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Original scientific paper

REMOTE DETECTION OF RAGWEED (AMBROSIA ARTEMISIIFOLIA L.)

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Abstract: The paper presents the contemporary findings of remote sensing regarding the control of common ragweed on agricultural land. The two-year research was performed in co-operation with the company Ciklonzacija Ltd., Serbia. The remote sensing process starts with the collection of images captured by several types of cameras equipped with special filters. Images are obtained by modified cameras mounted on helicopters, drones, and airplanes. Next, a special software is used to produce maps based on the obtained images that show the level of weed spread on agricultural land, illegal waste dumping areas, and other uncultivated areas, i.e. the areas that are potential sources of ragweed spread. The maps have a considerable economic benefit when mapping agricultural, wood, and other areas. Moreover, they reduce the use of human resources, and increase the capacity of data acquisition as well as the accuracy of the model of weed spread and its control.

Keywords: GIS; ragweed; remote detection; remote exploration; weeds

1 INTRODUCTION

Ambrosia artemisiifolia L. from the Asteraceae family, known as common ragweed, annual or low ragweed, is an annual weed. Due to its competitiveness, it causes direct agricultural losses. In addition, its pollen is a strong allergen and has an indirect negative effect. Thus, ragweed is cited as the most important weed nowadays [1-5]. It has been introduced from the North America to Europe [6, 7]. There are about twenty species of ragweed in Europe, with the common ragweed (Ambrosia elatior, Ambrosia artemisifolia) being the most dispersed. It has been spreading rapidly throughout Europe [8] at 6-20 km annually in the east-west direction. The pollen concentration in Croatia is measured in Zagreb and Osijek, whereas there are around 400 measurement points in Europe [9]. The highest level of ragweed infestation has been recorded on agricultural land, as it is shown in the research [10]. The spread of ragweed within a crop is determined by remote sensing [11]. Remote sensing, global positioning systems (GPS systems), and geographic information systems (GIS) are information technologies [12] with remote sensing being an indispensable method in various scientific fields. Thanks to the development of information technology, its results have been extensively used in numerous areas and a growing body of research [13, 14]. Remote sensing is often used for environmental research and activity monitoring [15, 16]. It is the science of acquisition of information about an object or phenomenon without maintaining any physical contact. According to [17, 18], it is usually performed from land-based, air-based, and satellite-based platforms. Remote sensing increases the capacity of data acquisition as well as the accuracy of the model of infestation and spread [19]. The research [20] stipulates that remote sensing of ragweed is performed on areas as large as 1 ha and bigger. Visual data interpretation, also known as photointerpretation, is the identification and delimitation of the depicted objects. Visual interpretation facilitates an analysis of imagery at every level of categorization, thus enhancing the processing of digital photos. The recognition of the differences among the objects and environment implies a comparison based on one or more basic elements or phenomena in the surveyed environment, as stipulated by [21, 22]. Furthermore, the spatial information system is used for the acquisition of spatial data that provide descriptive information. Additionally, GPS/GIS provides an accurate acquisition of numerous data on spatial and temporal variability. The accurate information on weed spread on agricultural and other types of land is a pre-requisite for efficient weed control. The objective of the research is to show the application of remote sensing in ragweed control on agricultural land. Remote sensing detects both the spread of ragweed and it provides faster and efficient mapping. It was performed from the air using diverse types of cameras with special filters. Then, based on the acquired data, maps were created using a special software. While capturing the images of the ragweed infected agricultural land, illegal waste dumps and other uncultivated areas were surveyed for they are potential sources of ragweed spread. The obtained maps have a significant economic benefit when mapping agricultural land as well as woodland.

2 MATERIALS AND METHODS

Remote sensing was performed in co-operation with the company Ciklonizacija Ltd. in the areas of Apatin, Bački Breg, Petrovaradin, Sombor, Titel, and Veternik, Serbia, in 2015 and 2016. Ragweed remote sensing started with classification and monitoring followed by the correction of the classification results by visual interpretation and additional information. The objective of monitoring was to determine the circumstances of the spatial spread of ragweed based on the aerial images. The images can be obtained using helicopters, drones, or airplanes with a mounted modified camera. A Bell Jet Ranger helicopter (Fig 1) captured the RGB images, whereas a DJI Phantom 4 drone (Fig 2) captured the infrared images. Prior to the recording, the areas included in the research where checked. The researched ragweed-infested area must be homogenous, which implies a prominent level of similarity. To achieve proper classification and monitoring, it is necessary to have an

orthoimage, which is obtained from several images. The images of the surveyed areas were taken with a camera that records within the visible electromagnetic spectrum, whereas some sites were recorded by an NGB camera (Near Infrared, Green, and Blue), which records both in the visible and infrared (IR) part of the spectrum.

Figure 1 Helicopter "Bell Jet Ranger 203"

Figure 2 Drone DJI Phantom 4 Pro

Spatial resolution of aerial photos is a key factor. The higher the resolution, the more accurate is both the ragweed classification and the visual interpretation of the acquired images. The accuracy of ragweed spread detection determined by remote sensing is dependent on the season. A higher level of accuracy is achieved in summer, when ragweed retains more water in its leaves compared to other plants. Consequently, its leaves are greener, in which case a higher level of detection accuracy is achieved. Ref. [24] claims that plant pigmentation enables the identification of invasive plants based either on the cryophile content or the unique color of leaves and flowers. The paper shows the classification and monitoring as well as the correction of the classification results created by visual interpretation.

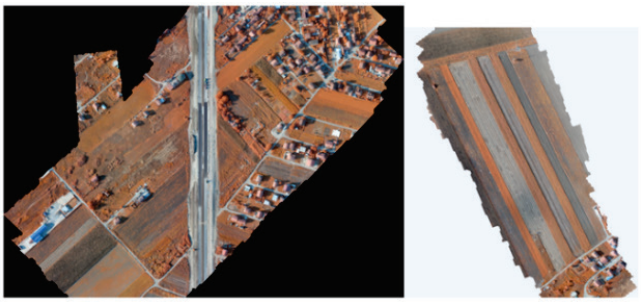

Figure 3 NGB Orthorectified aerial image acquired with an unmanned aerial vehicle

The first step in the classification process is the acquisition of ORTHO images and their subsequent orthorectification (Fig 3). Klisanski breg is the site which was subject to classification and monitoring. The photos were taken on the 14 September 2015 with a camera that records within the visible part of electromagnetic spectrum (Fig 4).

Figure 4 Aerial orthoimage of Klisanski breg

After the acquisition of orthorectified images, the following classes were defined to support the implementation of classification and monitoring (Fig 5): ragweed, fields, path, the surveyed agricultural culture, dry grass, and grass fields.

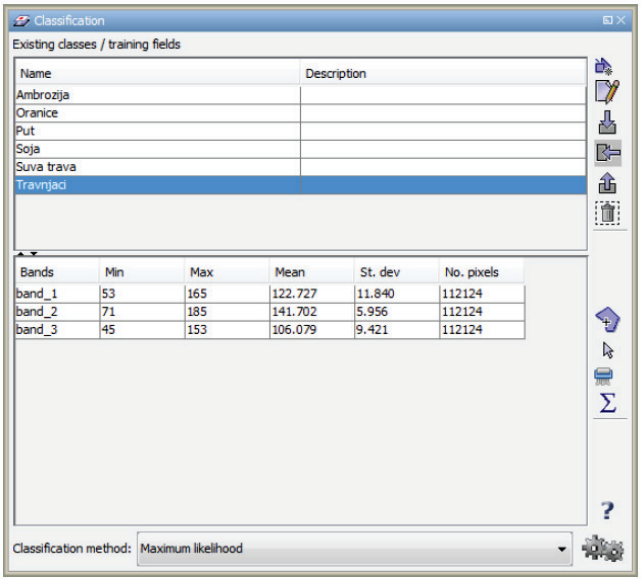

Figure 5 Definition of classes of interest

The contemporary programs Leo Works version 4.0.2.339, and SNAP, version 4.0. were used for image processing, whereas QGIS version 2.18.13 was used for the analysis of spatial data, and finally Agisoft PhotoScan version 1.3.4. was used to join the images. After the imagery acquisition, the classes required for the classification were defined. The next step was the assignment of sites to every defined class in the orthorectified aerial photo.

Fig 6. shows marked areas for every site under surveillance. Upon the selection of research sites for every class, a maximum probability method was applied to the classification with monitoring, which resulted in a thematic

map (Fig 7). Every class on the thematic map was assigned a certain color. Fig 7. shows the class of ragweed in the left frame marked in red, whereas the singled-out ragweed class marked in green is shown in the same picture on the right side. Following the application of classification with monitoring, a correction of classification results by visual information and additional information was performed.

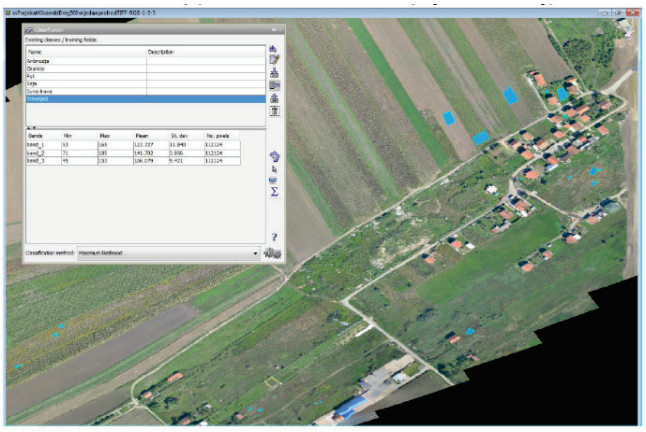

Figure 6 Selection of the surveyed area

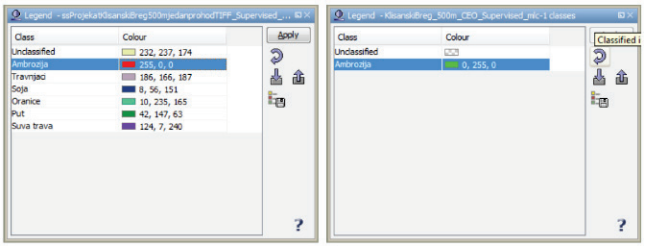

Figure 7 Thematic maps

A proper correction of the classification requires the knowledge of the appearance of certain sites in the orthorectified aerial photo. Information can be extracted from the photos obtained by remote sensing by isolating information based on visual interpretation of the photo or by semi-automatic computer processing. Mapping and land application are some of the ways of information extraction, whereas image classification and parameter calculation are the ways to extract information based on computer image processing. Nowadays, color recognition by the human eye has improved. An image can be analyzed, and information can be extracted in a direct and spontaneous way, or they can stem from a logical conclusion based on evidence. As far as spontaneous recognition is concerned, a farmer is expected to be able to notice and define a certain object faster and easier based on his previous professional experience. However, logical experience requires both previous professional knowledge and experience. The following interpretation elements are required to interpret a photo and to recognize certain objects: tone/color, texture, pattern, form, size, height/altitude, and location/association. The tone can be defined as relative brightness on a black and white photo. Different tones are important for image interpretation. The tone of the depicted object in a photo is directly related to the amount of light reflected against or emitted from the surface. Diverse types of rocks, lands, and vegetation have different tones. Thus, the differences in humidity levels can be discerned as the differences in tones. Consequently, higher humidity levels are discernible as dark gray tones. The differences among colors are related to the spectral features of the surveyed land. The advantage of color differences compared to tone differences results from a higher sensitivity of the human eye to color differences (approx. 10,000 colors) compared to tone sensitivity (approx. 200 tones of gray). Texture refers to the frequency of tonal change. It can be described as rough or fine, smooth or grainy, granulated, smudged, etc. and it is determined by the roughness of the area. Moreover, there is a significant relation between texture and the spatial sensor resolution. Pattern refers to the spatial arrangement of objects, and it implies a characteristic repetition of certain forms and relationships. It can be concentric, radial, etc. The form is a characteristic of many objects. A two-dimensional object projection and its height have an impact on the object depicted in a photo. The form of the object helps to identify it (i.e. paths, railways, agricultural fields). The size of an object can be observed in the absolute or relative sense. The width of a path can be estimated based on the comparison with the commonly known size of a vehicle. Additionally, the differences in heights facilitate the recognition of certain kinds of vegetation, types of buildings, etc.

Finally, location/association refers to the circumstances either on a site or relative to its environment. For example, the woods in mountains are different from those next to seas or rivers. A common use of these elements is crucial for visual interpretation (Fig. 8). Therefore, a standard classification of digital photos which relies solely on color is limited compared to visual interpretation.

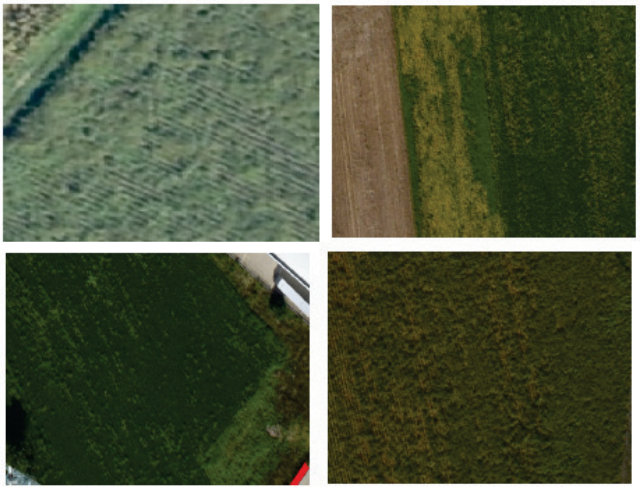

Figure 8 Ragweed within a soy field on the orthorectified image

3 RESULTS AND DISCUSSION

Remote sensing of ragweed spread after spraying involved the recording of locations with an NGB camera (NIR, green, and blue) in order to inspect them. The acquired images have revealed the healthy and uncut vegetation in orange, whereas the drying or cut ambrosia has been depicted

in pale tones of orange and gray color (Fig. 9). Additionally, based on the images, the BNDV index has been created, in which case a color palette has been added as an additional control of the sprayed area (Fig. 10).

Figure 9 Ragweed within a soy field on the orthorectified image

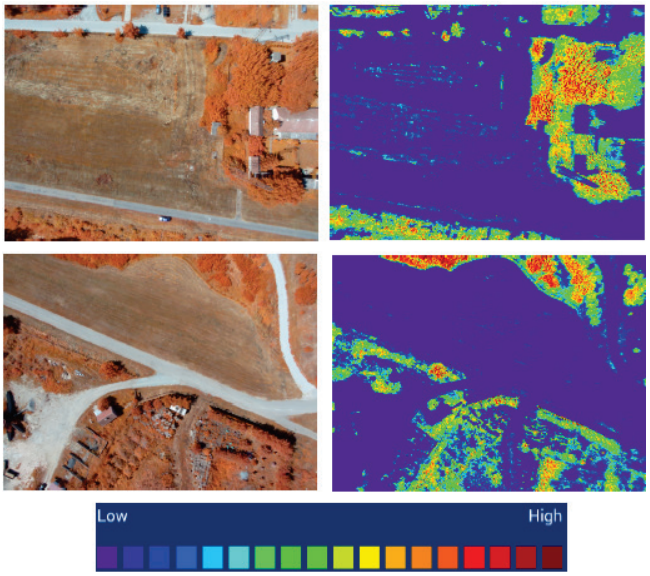

Figure 10 NGB images of cut areas (left) and BNDVI images (right)

The remote sensing of illegal waste dumps was accomplished through visual interpretation of an orthorectified aerial photo (Fig. 11) as well as by applying the NGRDVI index (Normalized Green Red Difference Vegetation Index) (Fig. 12) with the aim of providing potential support in the detection of differences between the vegetation, artificial objects, and unused land shown in the image. NGRDVI = 0 represents a boundary that helps to distinguish among the land covered with vegetation and other land areas (values of NGRDVI <0).

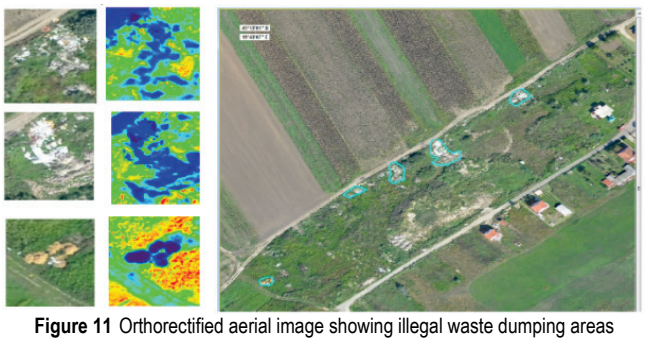

Figure 11 Orthorectified aerial image showing illegal waste dumping areas

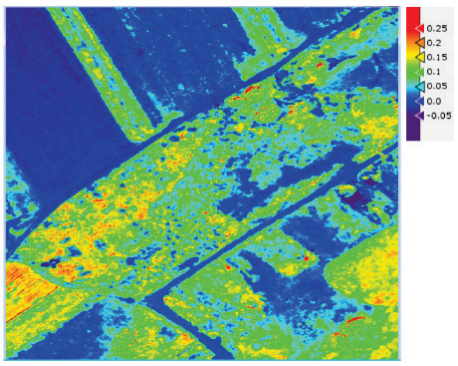

Figure 12 A Thematic map of the areas with the assigned color palette

4 CONCLUSIONS

Based on two years of research, the following conclusions can be drawn:

- By using the remote detection, a rapid, high quality and accurate insight into the spatial distribution of the ambrosia is obtained;
- The data processing makes possible to create precise maps of the ambrosia distribution;
- By repeating this method at certain time intervals we create prerequisites for reducing the occurrence and adverse effects of ambrosia for agricultural cultures and for humans as well;
- Due to the negative effect of ambrosia on agricultural crops and the human health issues (allergies) caused by ambrosia, the costs of remote detection are justified.

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Original scientific paper

THEORETICAL AND EXPERIMENTAL STUDY OF MUD INJECTION POROUS DRAINAGE IN FILTERS WITH FLOATING LOADING

Victor PROGULNY, Mikhail RYABKOV, Krystyna BORYSENKO, Igor GRACHOV

Abstract: The paper discusses up-flow filters with floating loading that intensify the process of filtering water for drinking purposes by improving filtering parameters and reducing power consumption. It is established that the problematic part of such filters are drainage systems. As a result of the analysis of drainage systems, it was found that the most promising material is porous polymer concrete. The proposed construction of drains is based on porous polymer concrete, which increases the reliability and durability of the filters with floating loading. The drainages based on porous polymer concrete, which intensify reliability and working life of filters, are offered. Mathematical model of the mud injection process of lower polymer concrete drainage with suspended matters, kept in damp water is designed. Experimental studies have shown the validity of the obtained model.

Keywords: filters with floating load; mud injection; polymer concrete drainage

1 INTRODUCTION

Water filtration through grain loadings is the most popular way of getting necessary water quality. Over the last years, the fast filters with floating loadings, which have a number of advantages in contrast to filters with sand loadings, have been spread due to the possibility of the reception of necessary quality water under the worst qualitative features of source water, absence of the capacities and pump for keeping and presenting of washing water, smaller number of utility systems and valves and pumping.

The most spread are filters with floating loadings with rising flow. The main advantage of such filters is that washing is produced by clean water from upper loading space. In the case of the lack of washing water, the upper loading spaces of several filters are united.

The filters include the upper drainage, consisting of metallic lattices with micromesh, expanded polystyrene loading and lower drainage produced of perforated asbestos-cement or plastic pipes.

The problematic part of such filters is the drainage system [2-4] due to the corrosion of metallic element of upper drainage-distributing system and to carrying away resin charge, which occurs quite often.

There are designs of these filters with drainage systems in the form of slotted pipes or caps. However, it is worth noting that these drains are not widely used due to the high costs [1].

According to the analysis of drainage systems in [1], the most promising material for drainage is porous polymer concrete. The reliability of the drainage systems from porous polymer concrete has been repeatedly proven not only in laboratory conditions, but also at the existing water treatment plants [5].

The polymer concrete material produced from granite gravel and epoxy resin of the mark ED-16 or ED-20is allowed by the Ukrainian Ministry of Health to be used in systems of drinking water-supply [5].

The use of polymer concrete drainage in filters with floating loading completely prevents the entrainment of loading grains, it does not contain metallic elements, and also reduces the overall height of the filter. However, the main issue that arises when using these structures is their possible mud injection with polluted water.

The novelty of this article is to develop the structures of polymer concrete drainage systems (section 2), to create a mathematical model of mud injection porous drainage with polluted water (section 3), and to confirm the mathematical model in the laboratory (section 4).

2 THE DRAINAGE SYSTEM OF A POROUS POLYMER CONCRETE IN FILTERS WITH FLOATING LOADING

In filters with floating loading, upper draining-distributing system can be made in the form of polymer concrete slabs put on supporting designs. Polymer concrete aggregate fineness is selected to prevent loading being carried away and to provide sufficient capacity discharge.

Lower drainage system can be made in the form of polymer concrete drainage tray-type [5], in which porous plates pack on supporting concrete walls, forming a pallet. Given design prevents carrying away filtering loading, provides the uniform collection of washing water and supply of damp water on filtration, as the bottom of the drainage has a variable section on length with the slope to collecting channel [6]. The thickness of upper and lower drainage porous polymer concrete layer is not more than 60 mm, and aggregate fineness is 3-5 mm.

General scheme of such filter is given in Fig. 1.At filtration, the source water is supplied to a lower drainage-distributing system 2, where it is distributed on the filter uniformly, gets through expanded polystyrene loading 1 and accumulates in the upper loading space, where it is drained off on pipe line 5 beyond the filter. At a wash-off, loading is prevented by upper drainage system 3. When washing, cleaned water from the upper loading layer moves downwards, washing off suspensions expanded polystyrene loading 1, and then is gathered in lower drainage-distributing system 2 and is conducted to pipe line 6.

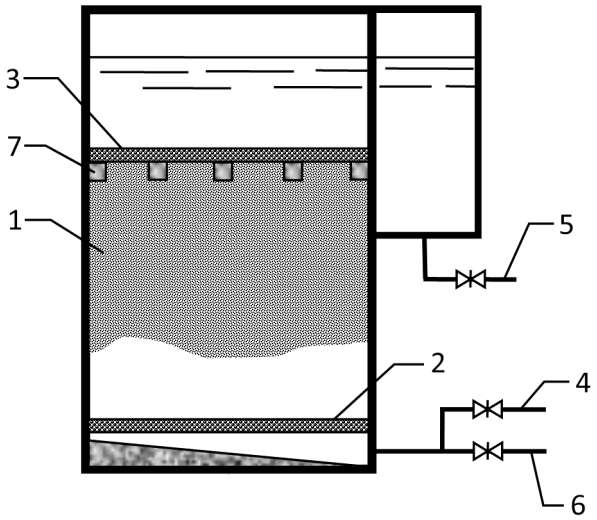

Figure1 The Scheme of the filter with floating loading with rising flow: 1 - floating loading; 2 - lower drainage system from porous polymer concrete of tray-type; 3 - upper drainage system from porous polymer concrete; 4 - supply of source water; 5 – product water bleed-off; 6 – bleed-off of wash water; 7 – supporting structures.

In the process of expanded filter polystyrene service with porous drainage, mud injection with suspension may occur, kept in damp water that will lead to the growing resistance. Therefore, this requires studying the mud injection process.

3 MATHEMATICAL MODELS OF THE DRAINAGE MUD INJECTION PROCESS WITH SUSPENSION

The process of low-concentrated suspension filtration through porous grain layer was studied by many authors. However, the model developed by D. M. Minc [7] is considered the most reliable. According to it, simultaneous removing of water contaminations and taking off earlier stuck particles occur under the influence of hydrodynamic power of the flow. The kinetics of this process is described by means of equations:

$$\frac{\partial \rho}{\partial t} = bVC - a\rho, \tag{1}$$

where $\rho(x, t)$and $C(x, t)$ – a mass concentrations setting in porous layer and suspension in fluid phase, variable on the coordinate x and at time t; b and a – parameters of filtration, defining intensity of the adhesion and particles take-off and depending from the filtration velocity V, layer density ρ, grains diameter and suspension characteristics adequately. Besides, D. M. Minc used the equation of the balance material under constant filtration velocity:

$$\frac{\partial \rho}{\partial t} = -V\frac{\partial C}{\partial x}, \tag{2}$$

The Eqs. (1) - (2) are solved at the condition:

$$C(0, t) = C_0; \rho(x, 0) = 0, \tag{3}$$

The solution of the system (1) - (3) and multiple experiences have enabled [6] obtaining the methods of technological modeling of the filtration process. Dependencies of filtration parameters have been found - a and b from velocity and grains size loadings d, typical for natural water purification practice.

At filtration of source water in filter with floating loading, polluted flow at the beginning gets through lower drainage, consisting of porous layer of coarse-grained material of small thickness. As suspension sizes of the particles are significantly smaller than the size of the pores ($d_B/d_n \le 1$), arising of the film from contamination on the partition surface is improbable. Evidently, resistance increasing will occur here in account of mud injection of porous space inside the layer.

In solving the problems, in accordance with filtration of polluted suspension through coarse-pore layer, the change of the overall amount of sediment setting at time is the most important, which can influence the carrying capacity of the porous layer. Less significant is the change of suspension concentration and setting on the layer thickness.

Such an approach allows simplification of the description of the mud injection process significantly and presupposes that suspension concentration on the layer thickness is slightly changed, i.e. $C \approx C_0$.

The conditions for such admissions are:

– Small thickness of the partition (up to 10-20 calibers of grains);

– Big (in ~3-5 times) fineness of grains in contrast to water purifying loadings filters.

In accordance with formula (1), the major effect in purifying the porous layer will be at the beginning of the cycle, when $\rho = 0$; in such a case:

$$C / C_0 = \exp(-bx), \tag{4}$$

Parameter bx according to D. M. Minc is proportional to value:

$$B = \frac{x}{d} Re^{-0.7},$$

where $Re = Vd/v$ – a number of Reynolds, v – kinematic liquid viscosity.

In water purifying on high-rate filter x/d value, the order is $(1–2)\times10^3$, but number is usually found within the range 1-4. Then B is a value of the order 10^3. For thick-grained thin layers parameter B = 20-50, consequently, bx for thick-grained partitions decreases 20-50 times in comparison with the loading of water purifying filter. If $b = 5$ m^{-1}, and $x = 0{,}7$ m [3], then in accordance with formula (4) $C/C_0 = 0{,}03$. At the reduction of bx 20-50 times, C/C_0 = 0,84–0,93. Consequently, suspension concentration on output from thick-porous fine layer is a little different from the input concentration that confirms the possibility of the suggestion $C \approx C_0$ usage.

In this case, Eq. (1) changes into common differential equation, which is easily integrated. The equation of the balance (2) in these conditions loses its sense and hereinafter is not used.

Taking into consideration the porous layer, which alternately works in mud injection mode, $C \approx C_0 > 0$, and then regeneration – $C \approx 0$. Such mode is typical for the considered problem, i.e. lower porous drainage filter with floating loading. The period length mud injection t_1 and regeneration period $-t_2$ are assumed. Since the flow velocity (as well as its direction) at mud injection and regenerations is different, then filtration periods and parameters will be diverse: for mud injection $-a_1$, b_1, for regeneration $-a_2$, b_2. Sediment content in partition is assumed at the beginning of mud injection ρ_{0k} then, integrating (1), we get:

$$\rho_k = C_0 V \frac{b_1}{a_1} - \left(C_0 V \frac{b_1}{a_1} - \rho_{0k} \right) \exp(-a_1 t), \tag{5}$$

The period of regeneration is described by equation:

$$\rho_p = \rho_{0p} \exp(-a_2 t), \tag{6}$$

where ρ_{0p} - a sediment concentration in porous partition at the beginning of regeneration, defined in (5) at $t = t_1$. The behavior of the change $\rho(t)$ in Eqs. (5) and (6) is shown in Fig. 2.

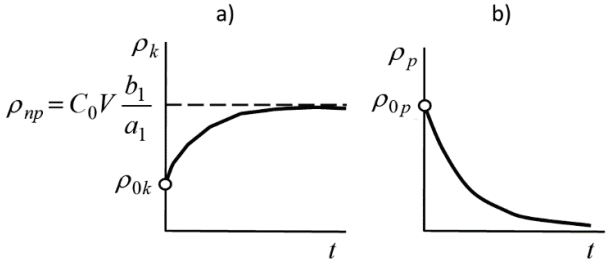

Figure 2 The dynamic pattern of the sediment concentration changes in the porous layer: mud injection (a), regeneration (b)

Run of a curve of mud injection (Fig. 2a) answers the physical ideas about the process: porous medium at $t \to \infty$ is silted up to a determined limit, and not unlimited. The similar effect - a limiting saturation of a porous space, at which velocities in pores are so great that further sediment fastening is already impossible - is noted at the analysis of the full model (1)-(3) D. M. Minc.

The value $\rho_{np} = C_0 V b_1 / a_1$ is identified as limiting saturation [6].

The run of the regeneration curve (Fig. 2b) shows that at $t \to \infty$ full removal of fixed sediment filler in pores can be reached. It can be explained that, as at regeneration (the mode of the fast filter washing), velocities of the motion speed of the fluid flow in the lower porous drainage vastly exceed the velocities at filtration, outwash from porous drainage accumulated for the period of suspension filter cycle occurs.

However, this differs from physical ideas about the process, in accordance to which zones can be in porous space, from where sediment will not be completely removed at given velocities. To overcome this contradiction, it should be considered that there is separated unwashed-out sediment ρ_n, depending on suspension features, structures of the porous medium and filtration velocities, and the above-mentioned description of the process obtained refers only to the washed-up form. It should be noted that suggestion about unwashed-out sediment corresponds to the two-component filtration models [8]. Then, under values ρ_k and ρ_p in Eqs. (5) and (6) we understand surplus on unwashed-out sediment of its amount. Consequently, formulas (5) and (6) can be used hereinafter without correction. It should be noted that ρ_n is a dynamic feature of the system, depending on suspension features, structures of the porous medium and filtration velocities [8]. Thus, to predict beforehand, the value ρ_n is impossible and it is necessary to undertake research studies.

With known parameters C_0, a_1, a_2, b_1, t_1, t_2 and ρ_n, it is possible to find values p_0 after any number of cycles. These calculations can be done manually, but they are easily solved using a PC.

When enumerated parameters remain to be unchangeable from cycle to cycle, it is possible to get quite a simple analytical decision.

$$\begin{aligned} \rho_{pi+1} &= e^{-T_2} \left[\rho_{np} (\rho_{np} - \rho_i) e^{-T_1} \right] = \\ &= e^{-T_2} \left[\rho_i e^{-T_1} + \rho_{np} (1 - e^{-T_1}) \right] = \rho_i e^{-T_1} + \rho_1, \end{aligned} \tag{7}$$

where $T = T_1 + T_2$; $T_1 = a_1 t_1$; $T_2 = a_2 t_2$. Sediment content after the first cycle:

$$\rho_{1=} \rho_{np} e^{-T_2} (1 - e^{-T_1}), \tag{8}$$

The Eq. (7) is a geometric progression, consequently, after N cycle:

$$\rho_N = \rho_1 \frac{1 - e^{-NT}}{1 - e^{-T}}, \tag{9}$$

and at $N \to \infty$:

$$\rho_\infty = \rho_1 (1 - e^{-T_1})^{-1}, \tag{10}$$

The full amount of delayed sediment taking into account unwashed-out part is defined by expression:

$$\rho_N = \rho_n + \rho_1 \frac{1 - e^{-NT}}{1 - e^{-T}}, \tag{11}$$

From the expression (11), it is seen that at $N \to \infty$ the amount delayed sediment ρ_N will tend to reach the maximum saturation of porous space. Consequently, in the process of operation, the porous drainage resistance increases to a defined limit, after that it stabilizes.

Thereby, the carried out approximate theoretical analysis indicates the possibility of the porous material use in design

of drainages of high-rate filter with floating loading, working with rising flow of water, but its experimental verification is necessary.

4 EXPERIMENTAL STUDIES OF THE MUD INJECTION PROCESS

Validity of the mathematical model was researched using the laboratory installation, the presenting model of the high-rise filter with floating polystyrene foam loading (Fig. 3).

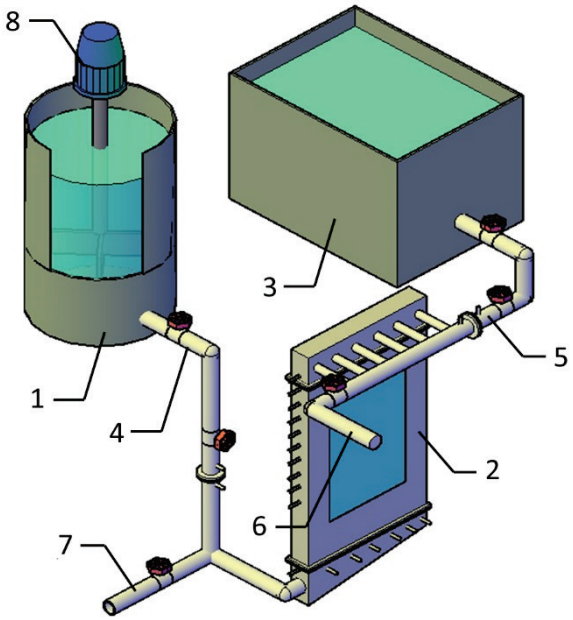

Figure 3 Scheme of laboratory installation for experimental studies of mud injection process: 1 – turbid water tank; 2 – filter; 3 – washing water tank; 4 – water supply pipeline for filtration; 5 – water supply pipeline for flushing; 6 – filtrate discharge pipeline; 7 –wash water discharge pipeline; 8 – mixer.

The installation comprised tank 1, in which water up to given concentration was clouded, and was supplied to the pipeline 4 into filter 2 in sizes 0.6×1.0×0.1 m. Then, passing the lower drainage, filtering loading and upper drainage, water was conducted on pipeline 6 beyond the filter. Supporting constant concentration of suspended materials in tank 1 was done by means of mechanical mixer 8. When washing clean water from tank 3 on pipeline 5 it went through filter 2, moved overhand-downwards and in pipeline 7 was conducted to its limits. For observation of the filtering level loading, the front filter wall was made transparent. Upper and lower drainages were made in the form of polymer concrete slabs with aggregate size 3-5 mm, thickness of 50 mm. Connecting material for polymer concrete aggregate was epoxy of the mark ED-20.

The experiment was conducted in two stages: in the beginning the hydraulic features of the drainages on clean water were researched, and in the second stage, mud injection dynamics with polluted water was researched.

The estimation of mud injection degree of porous polymer concrete was conducted with the comparison of the coefficient of the hydraulic resistance K with its initial importance K_0 [6], defined from the formula:

$$h = K\delta v^{2-n} V^n, \tag{12}$$

where h – loss of the pressure in the sample; δ – a sample thickness; v – coefficient of kinematic viscosity of water; n – factor degree, defined empirically.

The coefficient K in formula (12) depends neither on the flow velocity, nor on the water temperature, but it is defined with granulometric composition and laying of grains aggregates, as well as its porosity. At the pores, size changes because of porous layer mud injection, thus the coefficient K will be changed too. At constant filtering velocity and the temperature of the water is $K/K_0 = h/h_0$.

Foamy expanded polystyrene in size $d_э$ = 0,63-3 mm, d_{eq} = 1,25 mm and of layer height of 800 mm was accepted as the filtering loading.

Source water was clouded with silt from river Dnestr up to concentration 13-15 mg/l (the turbidity of water defined on photoelectric colorimeter KFK-2) and filtered at the speed of 7m/h. Washing the installation was conducted with clean water with the intensity 16-18 l/s·m^2 during 3-4 min.

While investigating polymer concrete dynamics with coagulated water 0.5% solution of the coagulant was prepared, as which alum sulphate was accepted. The received solution was mixed with previously clouded water and taken into filter 2. The dose of the coagulant varied within the range of 1-5 mg/l.

Fig. 4 presents a graph of the resistance changes of lower porous polymer concrete drainage at time $\overline{K}(t)$ for damp water, and in Fig. 5, using the coagulant dose from 1 to 5 mg/l is presented.

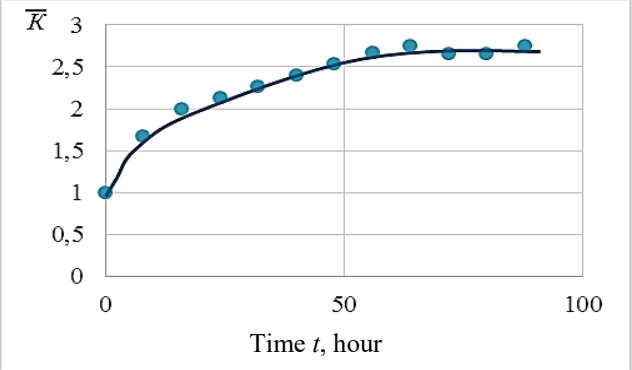

Figure 4 The graph dynamics of low polymerconcrete drainage with damp water.

The analysis of graphics in Fig. 4 shows that resistance of the lower drainage in the beginning grows, but then it is stabilized and hereinafter does not change under given filtering velocities and quality of source water. At that, relative coefficient of the hydraulic resistance grew approximately 2.7 times.

As can be seen in Fig. 5, nature of received curves is similar to graphic on Fig. 4. It should be noted that with the increasing of the coagulant dose, coefficient of the hydraulic resistance is higher. In such a case, mud injection degree and

maximum value $\overline{K}$ turned out to be higher here than at filtration of non-coagulated water. This circumstance can be explained, as contact coagulation occurs in polymer concrete pores. In this case, formed sediment has greater size and, consequently, silting up of polymer concrete drainage porous space takes place more intensively.

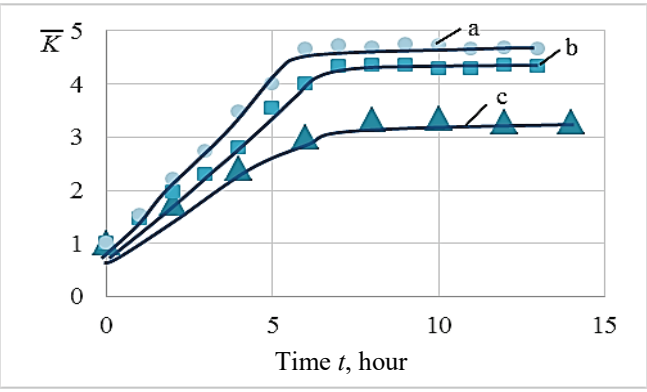

Figure 5 The graph dynamics of low polymer concrete drainage with damp water, using the coagulant: a - a dose of the coagulant 5 mg/l, b - a dose of the coagulant 3 mg/l, c -a dose of the coagulant 1 mg/l.

5 CONCLUSION

According to the analysis of drainage systems, it was found that the most promising material for drainage is porous polymer concrete. Designed drainage constructions based on polymer concrete in filters with floating loading will increase the reliability and durability of such filters. The obtained approximate mathematical description of porous drainages mud injection has confirmed it quite acceptable with experiments in the laboratory conditions and can be used for development of technological modeling methods of such processes.

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Original scientific paper

MODELING FOR THE ANALYSIS OF THE INVESTMENT POTENTIAL OF THE CONSTRUCTION SECTOR

Natalya SHLAFMAN, Kateryna FROLINA, Lovorka GOTAL DMITROVIC

Abstract: The purpose of the article is to develop a methodology for determining the need for the amount of investment resources needed to build the investment potential (IP) of the construction sector. The methodology is found in economic and mathematical modelling. We developed a model for the analysis of the investment potential of the construction sector (IPCS) by selecting the three-factor Cobb-Douglas production function for the IPCS study and by constructing a functional dependence from the collected statistical information, which allowed us to analyse the effect of changing the value of one of the selected factors on the resulting factor. The paper shows that market participants can use the proposed methodology to determine the factors that influence the improvement of IPCS, the degree of their influence and the determination of the values necessary to achieve a given level of investment potential.

Keywords: construction sector; investment potential; mathematical modelling; method of determining the need; three-factor production function

1 INTRODUCTION

In modern conditions, one of the sectors with the most demand by the society and the state in its social orientation and investment capacity is the construction sector. However, as it is the case with the entire Ukraine today, the construction sector is going through a difficult period marred by an unstable economic situation, innovations in the legislative framework and an undeveloped mechanism of work under the new rules, the energy crisis and the unwillingness to accept massive transition of enterprises to energy-saving technologies. The role of the investment policy in acquiring capital investments to increase the volume of construction work and to increase the investment potential of the construction sector in the Ukraine and its regions is more regressive than progressive. An important role in ensuring the growth of the socio-economic system through its stabilization and adaptation to the changing external and internal conditions is played by the system of state regulation. At the present stage of development, the construction sector increased multiple synergistic effects of the components preceding the rational process of the organization and management of construction. In fact, no significant investment and construction project is implemented today without the collaborative component at the level of management, resource and information interactions, design and construction processes and their documentary, regulatory and technical support.

The weak investment activity of the state, enterprises and the population, high intra-industry competition and the monopoly position of some construction companies, unnecessary administrative barriers, as well as imperfections in technical regulations, the imbalance of construction norms and regulations with the international standards negatively affect business activity in the construction industry. Thus, there is an objective need to intensify investment activity and to improve the methods of regulating investment processes and their compliance with the modern needs. Scientists pay enough attention to the definition of the concept of "investment" and the categories that create the conceptual apparatus of this direction of the economic science.

The theoretical aspects of investment and the issues of state regulation of the investment activity have been developed in the writings of authors such as: J. M. Keynes, [13], V. M. Lisyuk, [16], W. Sharpe, [25], A. Harrison, I. Love and M. S. Mc Millan, [11], E. J. Dolan and E. D. Lindsay, [5] and P. Masse [17]. In modern research, which marked a further development of the theory, the methodology and practice of investment in various economic activities include the following works: European Investment Bank [6], S. Gogiashvili [9], I. So and A. Staskevicius [26], O. I. Layko [15], D. Van Horn and D. Vahovich [28], L. J. Gitman [8], I. A. Blank [1], A. F. Hoiko [12] and O. D. Danilov, H. M. Ivashyna and O. H. Chumachenko [4].

However, despite a rather deep processing of many theoretical and methodological issues and practical research on the mechanisms of the state regulation of investment in different sectors of the economic activity, including the construction industry in the state, many questions remained outside of the scope of the research. Additionally, the current economic crisis requires new approaches in the solving of the problem of the intensifying investment activity.

Thus, the purpose of the article is to develop a methodology for determining the need for the volume of investment resources necessary to form the investment potential of the construction industry on the example of the Ukraine.

2 METHODOLOGY

The investment potential has the capacity to stabilize the construction industry at the macro and micro levels and increase the business activity. The research of investment problems is in the sight of many domestic and foreign scholars, but it should be noted that there is a significant difference in the interpretation of key concepts in the economic scientific literature and regulatory documents, and there is still no universal definition of them that would satisfy

the needs of both theory and practice. A basic and rather controversial concept in the investment paradigm of the construction sector is the concept of "investment", as there are many versions of it.

The term "investment" comes from the Latin word "invest" – to invest. R. Campbell, S. L. Brue and S. M. Flynn characterize investment as "the cost of production and accumulation of means of production and increase of material stocks" [2]. W. F. Sharp, G. J. Aleksander and J. V. Beyli believe that the term "investment" should mean a categorical abandonment of the present good for a (possible) value in the future [24]. L. J. Gitman has a less categorical idea when it comes to investing. His investment is seen as a way to save capital for the future by placing the initial capital in various forms [8].

Some scientists, such as J. S. Merkulov [19], S. V. Mocherny [20], A. M. Moroz [21], O. F. Pokropivny [23], D. M. Chervanov [3], whose scientific interests are mainly related to investments, treat investments as long-term investments. They argue that only through long-term capital investment can business income be achieved. It is possible that such views have arisen due to the influence of the scientific and official thought from the time of transition to a market economy, when the category of "investment" at the official level was not fully justified and considered, but what was considered was the concept of "capital investment", exclusively as an expense for the creation of new fixed assets, their expansion, reconstruction and renovation, which "were implemented in the form of long-term capital investments in various sectors of the economy" [14]. Investments are a category of financial markets that can exist and occur only in the process of distributing the inter-object redistribution of funds.

Such approaches, in our opinion, reject the possibility of short-term investments (up to one year). The current practice of investing in projects with a short-term return on capital in the face of prolonged inflationary processes and high investment risks that are characteristic of the Ukraine is entirely appropriate. Additionally, it is not necessary to identify "investments" with "capital investments", because capital investment is one of the forms of investment which is considered in the context of this study as a means for housing construction. Investments are the same as current assets, intangible assets (patents, licenses), financial instruments, etc.

In foreign economic literature, the term "investment" is emphasized as an important feature in terms of the ability of the investment process to generate revenue. Thus, the French economist P. Masse argues that the act of capital investment is an act of exchange to meet the today's need for the expectations of satisfying it in the future with the help of the invested goods [17]. E. J. Dolan and D. Lindsey define investment as "an increase in the amount of capital that functions in the economic system, that is, an increase in the supply of productive resources" [5].

According to the definition given by I. A. Blank, "Investment company – investing capital in all its forms in various objects (tools) i.e. business for profit and to achieve economic or non-economic effects, the implementation of which is based on market principles and due to the time factor, risk and liquidity" [1].

Therefore, most authors identify the purpose of the investment process, but do not specify the objects of investment and do not determine the nature of investment (financial, material or intellectual). In general, the emphasis on the anticipation of an increase in future capital is predominant in determining investment.

In our opinion, in today's business environment, for the realization of its economic goals, it is not enough to focus solely on profit. Long-term development involves a move towards social responsibility, which not only creates a positive image of the company, but also reduces operational risks, expands the market and increases the investment rating. Investing can cause not only economic benefits, but also an environmental and social impact.

In the writings of Western economists, investment is studied as a unity of two aspects: resources (capital values) and investments (expenses). The most complete approach is presented in the writings of the Nobel Prize laureate J. M. Keynes. He understood investment as "... the current increase in the value of capital assets as a result of the production activity of this period." This is – "... the part of the profit for a certain period that was not used for consumption." [13] However, if funds are not in circulation, it simultaneously reduces their value as a result of inflation, and on a global scale the turnover is reduced, which thus contributes to the crisis. We believe that investing is a process of attracting accumulated capital into circulation in order to generate income or benefit.

Additionally, it is believed that investment is only an investment of money, which is hard to agree with, since such operations can be carried out not only in monetary terms but also in other forms – various instruments of the stock market, intangible assets, real estate, technologies, etc. However, unused funds cannot always be attributed to investment since money, which is lagging behind and is not in circulation, cannot bring a positive value of profit and lose its value under the influence of certain factors, among which inflation is the most widespread. Therefore, we consider the appropriated interpretation of investments as a direct process of transformation into the cost of accumulated capital to obtain a certain useful effect or income.

In view of the above-mentioned investments, they should be characterized as investments (financial, material, intellectual), i.e. costs that will after some time lead to the multiplication of wealth; but income is not considered as a motive of investment activity. Investments are the essence of the time derivative of savings – what accumulates today will bring revenue tomorrow, however, the opposite will also be true – what brings profit today will in the future enable the creation of capital.

Thus, the difference between the two categories is rather conditional, but it will still allow the concept of investments in the formation of capital to be equated with the fact that it generates income on the invested capital at a given time. The motives for investing and saving various recipients are determined by the sum of factors: economic (inflation, tax policy, monetary policy), political (legislative measures,

legal basis of investment, stability of state regulation in general), scientific and technical (level of development of technology, industrial potential), socio-economic, etc.; and also the factors of the micro-environment: availability of investment instruments, level of investment competition in the investment market, resource sufficiency, etc.

Based on the results of the analysis of definitions, we see investments as a target, a timely investment of financial, material and intellectual resources in the development of business or other business entity in order to obtain an economic, social or other effect.

Our judgments about the essence of investment activity for the construction industry are based on the disclosure of this category as targeted actions aimed at finding, evaluating and selecting potential investment objects, as well as entering into agreements relating to their acquisition or financing and ensuring a return on investment from the purpose of forming a safe and comfortable living environment, providing effective financial, economic and technical indicators of the activity of construction enterprises.

In general, the investment system of the construction industry is defined as a complex of interconnected elements of the regulatory legal form, formal and informal norms and rules of organization of the work of subjects and objects of the investment process in the implementation of their investments and in the organization of the production process (reproduction of capital) [15].

For the study of state regulation of the construction industry, it is important to define the definition of "investment potential". According to V. M. Grinyova et al. investment potential is "…an opportunity to invest for furthering its growth or investment opportunities to conduct, support or preserve anything" [10].

Under investment potential, V. I. Zubkova et al., perceive "... a set of financial and investment resources of the enterprise, allowing them to carry out an effective investment activity aimed at ensuring its efficient and sustainable business activities" [29].

K. P. Pokatayeva defines the investment potential of the enterprise as an organized set of available economic resources [22]. The investment potential of the country accumulates the investment potentials of all regions, industries and businesses. Between the potentials of different levels as sets is the relation of attachment and intersection. When determining the investment potential at all levels of the economic activity, its main macroeconomic, socio-demographic and other characteristics are taken into account, and it is generalized and acts as a weighted sum of partial potentials.

Capital investment in the construction sector contributes to the solving of the most important issue – providing housing for the population. In general, this issue should be considered not only from the point of view of solving social problems in the state, but also from the point of view of expanding the market of production of many enterprises which are affiliated with the construction industry – the production of building materials, furniture, glass, window constructions, home appliances, sets of products for the needs of housing and communal services, etc. Namely, the construction industry prompts cooperation and promotes the development of related industries.

The construction sector, especially its housing sector, is also able to function during the times of economic crisis, as the demand for housing, along with the involvement in the construction of funds is always there. The construction of housing promotes the development of regions, increases employment, contributes to the fight against unemployment and increases the welfare of the population. In the Ukraine, as well as in other developed countries, capital investments are largely filled with money from the population, and foreign investments may be desirable to focus on the formation of large and accessible-to-all segments of the population rental housing market. For the Ukrainian partners of Western investment companies, the rental property market is a guarantee of spare and relatively stable assets for the investment in construction. Additionally, the construction of rental housing positively affects the behaviour of the society, its economic development, and it stimulates the development of other industries.

The investment potential of the Ukrainian construction sector is today mainly localized in the area of residential buildings, as there is a demand for these objects among the population; while industrial, social and communal construction work is practically not conducted due to lack of investment. During a crisis of the Ukrainian economy, investors, both foreign and domestic, will not risk investing their financial resources in the construction and the creation of production facilities, as there is no guarantee of their use and payback.

Today, scientists and experts agree that in the near future, until the economic situation in the country does not stabilize, one should not expect the arrival of investments in the construction industry. The construction of social facilities (kindergartens, hospitals, schools) and the communal infrastructure is entirely dependent on the filling of local budgets and the desire of the local authorities to create and repair these objects, as well as on the state of the development of partnership in investment activities between the local authorities and entrepreneurship in the construction industry.

Currently, foreign investment in the construction sector in the Ukraine is insignificant (3% in 2015). A foreign investor is best placed to invest in the Ukrainian real estate, because prices in the Ukraine are still lower than in Europe, and the authorities emit a good attitude and are willing to cooperate with foreign businessmen investing in the Ukrainian economy. The actions of investors in this direction will stimulate the employment of the population of cities and regions, they will also promote decentralization processes because they will fill local budgets with taxes and, most importantly, they will contribute to the growth of the investment potential of the construction sector as a whole.

Consequently, it is necessary to analyse and evaluate the investment potential of the construction industry, especially the industrial construction sector and the construction of infrastructure objects, such as industrial, transport, and social objects.

3 THE MODEL

In order to assess the investment potential, it is necessary to substantiate the indicators used to determine the process of capital investment and its developments in the industry, and changes in the volume of construction work that was observed not only in the past, but also needs to be observed in terms of future opportunities. To construct a model for analysing the investment potential of the construction industry in order to make a rational decision, we will initially conduct studies in which we will define a system of formalized factors that will allow the local governments to choose the best of the proposed alternatives in terms of regional significance, strategic feasibility and investment effectiveness of the impact on the investment potential of the construction industry. Determining the need for the total amount of investment resources necessary for the formation of investment potential is an important part of the state regulation of investment activity of construction organizations and it is being developed in a phased manner.

3.1 Selection of Formalized Factors, Essential in Terms of Building the Investment Potential of the Construction Industry

Theoretically, the number of factors for constructing a model of an analysis that could be selected to determine the investment potential of the construction sector is quite significant, because its investment potential is shaped by the following factors: natural, socio-labour, innovation, economic, institutional, infrastructural, financial and consumer resources, etc. However, the application of a number of provisions of the theory of systems, namely the principles of the necessary variety of system elements, the minimum sufficiency and the target orientation of these elements allow you to limit their number.

The choice of formal factors significant in terms of increasing the investment potential of the construction industry will be based on the availability and accessibility of statistical information.

According to research of the National Institute for Strategic Studies under the President of the Ukraine, the level of the investment (use) of capital investments is highlighted by the level of investment attractiveness of the industry, and among the main factors influencing the formation of the investors' preferences and the formation of the investment potential of the industry are the attraction of foreign direct investment and the state of fixed assets.

In modelling the investment potential of the construction industry as the initial characteristics of the model, we will consider the growth rate of capital investments (the ratio of the investment volume for the current year to the volume of investments in the previous period).

The main determinants of the impact on the investment potential of the construction industry are as follows:

- the growth rate of foreign direct investment (equity) (calculated as the ratio of annual FDI inflows to the sector in the current year to the amount of the previous year),

- the growth rate of construction (the indicator of the dynamics of construction, calculated as the ratio of the volume of construction work performed in the current year to the volume of construction work in the previous year (the index of the volume of construction works)),

- the growth factor of fixed assets of the industry (ratio of the amount of fixed assets at the end of the year to their value at the beginning of the year).

3.2 Selecting a Mathematical Model and Collecting the Necessary Information

Research of the investment potential of the construction industry is carried out with the help of a three-factor production function $Y = F(X_1, X_2, X_3)$.

Calculations of the components in the assessment of the investment attractiveness of the construction industry are based on the information of the State Statistics Service of the Ukraine and are shown in Table1.

It should be noted that in 2014, foreign direct investment in the Ukraine decreased significantly due to a sharp drop in hryvnia and the outflow of equity.

Table 1 Indicators for the analysis of the investment potential of the construction industry [27]

Year	Indexes			
	The growth rate of capital investment	The growth rate of foreign direct investment (equity)	The growth rate of construction	The growth factor of fixed assets of the industry
	Y_i	X_{1i}	X_{2i}	X_{3i}
2001	1.40	1.30	0.90	1.01
2002	1.64	1.40	0.84	1.02
2003	1.37	1.44	1.15	1.08
2004	1.88	1.73	1.10	1.04
2005	1.09	3.48	0.93	1.10
2006	1.28	0.60	1.09	1.21
2007	1.47	1.68	1.10	1.28
2008	1.37	0.77	0.85	1.41
2009	0.49	0.70	0.40	1.10
2010	0.93	1.07	0.79	1.03
2011	1.72	1.16	1.16	1.17
2012	0.97	0.90	0.92	1.02
2013	1.08	0.58	0.89	1.17
2014	0.98	0.001	0.78	0.99

3.3 Conducting Calculations

Construction of a three-factor production function

We are aware of the statistical data of individual components of the investment potential of the industry for the n previous periods.

Y – factor resulting in the investment potential of the construction industry;

X_1, X_2, X_3 – key factors of the investment potential.

Let us denote:

Y_i – the value of the resulting factor in the i-period;

X_{ji} – the value of the j-factor in that i-period.

Tab. 1 will in the symbolic form have the following form (Tab. 2).

Table 2 Values of the factors studied

No.	Y	X_1	X_2	X_3
1	Y_1	X_{11}	X_{21}	X_{31}
2	Y_2	X_{12}	X_{22}	X_{32}
.....				
i	Y_i	X_{ji}	X_{ji}	X_{ji}
.....				
n	Y_n	X_{1n}	X_{2n}	X_{3n}

Tab. 2 actually establishes a functional relationship between the resulting factor Y and factors X_1, X_2, X_3, i.e. Y is a function of three variables.

The given functional dependence is represented by a formula based on the theory of production functions, which was developed by American scholars D. Cobb and P. Douglas, who proposed one of the most well-known varieties of production functions, called the function of Cobb-Douglas.

General view of this feature:

$$Y = A\prod_{i=1}^{n} x_i^a \tag{1}$$

where Y – resultant factor;
A – numerical parameter of the production function;
X_i – i^{th} argument, i.e., the value of the i^{th} factor of the production function;
a_i – index of the degree of the i^{th} argument.

In our case, we will have:

$$Y = AX_1^{a_1}X_2^{a_2}X_3^{a_3} \tag{2}$$

By performing logarithmic operations (2), we get:

$$\ln Y = \ln A + a_1\ln X_1 + a_2\ln X_2 + a_3\ln X_3 \tag{3}$$

or after the replacement: $\ln Y = y$, $\ln A = a_0$, $\ln X_1 = x_1$, $\ln X_2 = x_2$, $\ln X_3 = x_3$

$$y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 \tag{4}$$

Let us denote through $y_i = \ln Y_i$, $x_{ij} = \ln X_i (i = 1, \dots, n)$, $(j = 1, 2, 3)$ – the value of the new variables in the i^{th} period.

Eq. (4) for the i^{th} period takes the form:

$$y = a_0 + a_1x_{1i} + a_2x_{2i} + a_3x_{3i} \ \ (i = 1, \dots, n) \tag{5}$$

In fact, (5) is a system of linear algebraic equations. Such a system for $n > 4$, according to the Kronecker-Capelli theorem, has no precise solution, so we will try to (5) execute approximately, but with the slightest error.

$$y_i \approx a_0 + a_1x_{1i} + a_2x_{2i} + a_3x_{3i} \tag{6}$$

Apply to (6) the method of least squares. To do this, we write the target function:

$$S = \sum_{i=1}^{n}[y_i - a_0 - a_1x_{1i} - a_2x_{2i} - a_3x_{3i}] \to min \tag{7}$$

where $S = S(a_0, a_1, a_2, a_3)$.

According to Fermat's theorem for finding the extremum of the function S, we find its partial derivatives and equate to zero:

$$\begin{cases} \frac{dS}{da_0} = -2\sum_{i=1}^{n}[y_i - a_0 - a_1x_{1i} - a_2x_{2i} - a_3x_{3i}] = 0 \\ \frac{dS}{da_1} = -2\sum_{i=1}^{n}[y_i - a_0 - a_1x_{1i} - a_2x_{2i} - a_3x_{3i}]x_{1i} = 0 \\ \frac{dS}{da_2} = -2\sum_{i=1}^{n}[y_i - a_0 - a_1x_{1i} - a_2x_{2i} - a_3x_{3i}]x_{2i} = 0 \\ \frac{dS}{da_3} = -2\sum_{i=1}^{n}[y_i - a_0 - a_1x_{1i} - a_2x_{2i} - a_3x_{3i}]x_{3i} = 0 \end{cases} \tag{8}$$

After the transformations, we will have:

$$\begin{gathered} a_0n + a_1\sum_{i=1}^{n}x_{1i} + a_2\sum_{i=1}^{n}x_{2i} + a_3\sum_{i=1}^{n}x_{3i} = \sum_{i=1}^{n}y_i \\ a_0\sum_{i=1}^{n}x_{1i} + a_1\sum_{i=1}^{n}x_{1i}^2 + a_2\sum_{i=1}^{n}x_{1i}x_{2i} + \\ +a_3\sum_{i=1}^{n}x_{1i}x_{3i} = \sum_{i=1}^{n}y_{1i}y_i \\ a_0\sum_{i=1}^{n}x_{2i} + a_1\sum_{i=1}^{n}x_{1i}x_{2i} + a_2\sum_{i=1}^{n}x_{2i}^2 + \\ +a_3\sum_{i=1}^{n}x_{2i}x_{3i} = \sum_{i=1}^{n}y_iy_{2i} \\ a_0\sum_{i=1}^{n}x_{3i} + a_1\sum_{i=1}^{n}x_{1i}x_{3i} + a_2\sum_{i=1}^{n}x_{2i}x_{3i} + \\ +a_3\sum_{i=1}^{n}x_{3i}^2 = \sum_{i=1}^{n}y_iy_{3i} \end{gathered} \tag{9}$$

or in the matrix form ($\boldsymbol{B}$):

$$\begin{pmatrix} n & \sum_{i=1}^{n}x_{1i} & \sum_{i=1}^{n}x_{2i} & \sum_{i=1}^{n}x_{3i} \\ \sum_{i=1}^{n}x_{1i} & \sum_{i=1}^{n}x_{1i}^2 & \sum_{i=1}^{n}x_{1i}x_{2i} & \sum_{i=1}^{n}x_{1i}x_{3i} \\ \sum_{i=1}^{n}x_{2i} & \sum_{i=1}^{n}x_{1i}x_{2i} & \sum_{i=1}^{n}x_{2i}^2 & \sum_{i=1}^{n}x_{2i}x_{3i} \\ \sum_{i=1}^{n}x_{3i} & \sum_{i=1}^{n}x_{1i}x_{3i} & \sum_{i=1}^{n}x_{2i}x_{3i} & \sum_{i=1}^{n}x_{3i}^2 \end{pmatrix}\begin{pmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{pmatrix} =$$

$$= \begin{pmatrix} \sum_{i=1}^{n}y_i \\ \sum_{i=1}^{n}y_i\,x_{1i} \\ \sum_{i=1}^{n}y_i\,x_{2i} \\ \sum_{i=1}^{n}y_i\,x_{3i} \end{pmatrix} \tag{10}$$

By the method of the inverse matrix (10), we find the components of the desired vector a_0, a_1, a_2, a_3. From here: $A = e^{a_0}$.

Numerical calculations

We are building the matrix $\boldsymbol{B}$:

$$\boldsymbol{B} = \begin{pmatrix} n & \sum_{i=1}^{n}x_{1i} & \sum_{i=1}^{n}x_{2i} & \sum_{i=1}^{n}x_{3i} \\ \sum_{i=1}^{n}x_{1i} & \sum_{i=1}^{n}x_{1i}^2 & \sum_{i=1}^{n}x_{1i}x_{2i} & \sum_{i=1}^{n}x_{1i}x_{3i} \\ \sum_{i=1}^{n}x_{2i} & \sum_{i=1}^{n}x_{1i}x_{2i} & \sum_{i=1}^{n}x_{2i}^2 & \sum_{i=1}^{n}x_{2i}x_{3i} \\ \sum_{i=1}^{n}x_{3i} & \sum_{i=1}^{n}x_{1i}x_{3i} & \sum_{i=1}^{n}x_{2i}x_{3i} & \sum_{i=1}^{n}x_{3i}^2 \end{pmatrix} =$$

$$= \begin{pmatrix} 14 & -5.1978 & -1.5502 & 1.4694 \\ -5.1978 & 50.9610 & 2.0984 & 0.0758 \\ -1.5502 & 2.0984 & 1.1178 & -0.1021 \\ 1.4694 & 0.0758 & -0.1021 & 0.2912 \end{pmatrix}$$

$$b = \begin{pmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{pmatrix} = \begin{pmatrix} 2.5946 \\ 1.2697 \\ 0.7329 \\ 0.3452 \end{pmatrix} \quad (11)$$

The inverse matrix $\acute{A}^{-1}$will look as:

$$\boldsymbol{B}^{-1} = \begin{pmatrix} 0.1877 & 0.0142 & 0.1517 & -0.8977 \\ 0.0142 & 0.0225 & -0.0305 & -0.0884 \\ 0.1517 & -0.0305 & 1.1292 & -0.3616 \\ -0.8977 & -0.0884 & -0.3616 & 7.8592 \end{pmatrix}$$

Then

$$\begin{pmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{pmatrix} = \boldsymbol{B}^{-1} b = \begin{pmatrix} 0.3064 \\ 0.0126 \\ 1.0576 \\ 0.0067 \end{pmatrix} \quad (12)$$

From here: $A=e^{a_0}=e^{0.3064}=1.3585$

Thus, Eq. (2) will have the following form:

$$Y = 1.3585 X_1^{0.0126} X_2^{1.0576} X_3^{0.0067} \quad (13)$$

3.4 Drawing Conclusions

The obtained functional dependence allows us to carry out an analysis of the effect of changing the value of one of the selected factors (X_1, X_2, X_3) on the resulting factor Y. Thus, according to the results of the research of the National Institute for Strategic Studies under the President of the Ukraine, the main factors shaping the investment potential of the industry are "the rate of growth of foreign direct investment (equity)" (X_1) which affects a little, but the influence of the factor of "the coefficient of growth of the fixed assets of the industry" (X_3) is almost absent. The factor of "the growth rate of construction" (X_2) affects significantly the resulting factor of "the rate of growth of capital investment".

Given that the average factor of the "growth factor of the fixed assets of the industry" (X_3) is 1.12 (from the Tab. 1), $1.12^{0,0067} = 1.0008 \approx 1$ and the impact on the performance indicator is small, functional dependence can then be expressed:

$$Y = 1.3585 X_1^{0.0126} X_2^{1.0576} \quad (14)$$

Graphic interpretation of the obtained Eq. (14) gives a visual representation of the nature of the factors' dependence: "the rate of growth of capital investment" (Y), "the growth rate of foreign direct investment (equity)" (X_1) and "the growth rate of construction" (X_2) as shown in Fig. 1.

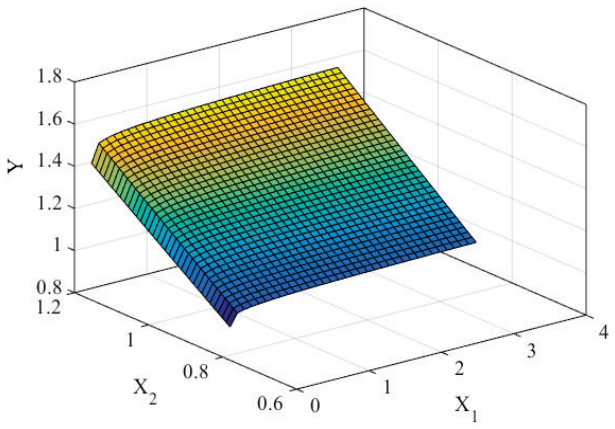

Figure 1 Graphic interpretation of functional dependence

The average value $X_1^{0.0126}$ ($1.2^{0.0126}$)equals 1.0023≈1, and as a result we get the following functional dependence of the resulting factor on the "growth rate of construction", which significantly affects it:

$$Y = 1.3585 X_2^{1.0576} \quad (15)$$

The graph of function (15) will be a straight line passing through the origin.

Thus, the factors X_1, X_3 do not have a significant impact on the resultant indicator of "the rate of growth of capital investment", and in subsequent studies and calculations, they cannot be taken into account.

Factor X_2 – The "growth rate of construction" significantly affects the "growth rate of capital investment", which characterizes the investment potential of the industry, and the functional dependence has the form (15) (with an increase of X_2 by 1, Y will increase by 1.3585 times).

Thus, the sensitivity of the volume of construction products to the integral indicator of capital investment in the construction sector is growing to a large extent. Therefore, the decision to increase the volume of construction products is effective in changing the approaches towards increasing the investment potential and hence towards the formation of an investment policy.

We shall now consider the properties of the characteristics of the function (13).

1. Factors' elasticity. These figures show by how many percent will Y change if X_i is increased by 1%, leaving other factors unchanged.

For the 1st factor we get

$$E_{x1} = \frac{x_1 \frac{aY}{ax_1}}{Y} = \frac{x_1 A a_1 X_1^{a_1-1} X_2^{a_2} X_3^{a_3}}{Y} = \frac{a_1 A X_1^{a_1} X_2^{a_2} X_3^{a_3}}{Y} = \frac{a_1 Y}{Y} = a_1 \quad (16)$$

where E_{x_1} – elasticity of the 1st factor.

Thus, for the i^{th} factor, we obtain

$$E_{xj} = a_j \quad (17)$$

If X_2 – the growth rate of construction increases by1%, leaving other factors unchanged, then Y – the growth rate of capital investment will increase by 1.0576%. Similarly, with an increase of 1% for X_1 – the growth rate of direct foreign investment (equity) or X_3 – the growth factor of the fixed assets of the industry, Y will increase – the growth rate of capital investments by 0.0126% and 0.0067%, respectively.

2. Limiting factor productivity. With an increase of the i^{th} factor per unit, the resultant factor will increase by a magnitude of $\frac{\partial Y}{\partial X_i}$. In practice, when planning incomes and expenditures, it is often erroneously believed that the magnitude of the increase is $\frac{Y}{X_i}$.

Therefore, for the 1st factor we get a similar result as for the 2nd and 3rd factors.

$$\frac{\partial Y}{\partial X} = a_1 A X_1^{a_1-1} X_2^{a_2} X_3^{a_3}$$

$$\frac{Y}{X_1} = A X_1^{a_1-1} X_2^{a_2} X_3^{a_3} \quad (18)$$

$\frac{\partial Y}{\partial X_1} = a_1 \frac{Y}{X_1}$ that is to say $\frac{\partial Y}{\partial X_1} \leq \frac{Y}{X_1}$

3. Determining the values of the factors necessary to achieve a given resultant factor. Find the minimum values of the factors X_1, X_2, X_3, required to achieve a given Y. To do this, we have the following problem of nonlinear programming:

$$\begin{cases} I = X_1 + X_2 + X_3 \to min \\ A X_1^{a_1} X_2^{a_2} X_3^{a_3} = Y \\ X_1;\ X_2;\ X_3 \geq 0 \end{cases} \quad (19)$$

To solve it, we apply the Lagrange multiplier method.

$$L(X_1; X_2; X_3) = \\ = X_1 + X_2 + X_3 + \lambda[Y - A X_1^{a_1} X_2^{a_2} X_3^{a_3}] \to max \quad (20)$$

$$\begin{cases} \frac{dL}{dX_1} = 1 - \lambda\left(a_1 A X_1^{a_1-1} X_2^{a_2} X_3^{a_3}\right) = 0 \\ \frac{dL}{dX_2} = 1 - \lambda\left(a_2 A X_1^{a_1} X_2^{a_2-1} X_3^{a_3}\right) = 0 \\ \frac{dL}{dX_3} = 1 - \lambda\left(a_3 A X_1^{a_1} X_2^{a_2} X_3^{a_3-1}\right) = 0 \\ \frac{dL}{dX_1} = Y - A X_1^{a_1} X_2^{a_2} X_3^{a_3} = 0 \end{cases} \quad (21)$$

Conditions of optimality

$$\frac{1}{\lambda} = a_1 A X_1^{a_1-1} X_2^{a_2} X_3^{a_3} = a_2 A X_1^{a_1} X_2^{a_2-1} X_3^{a_3} = \\ = a_1 A X_1^{a_1} X_2^{a_2} X_3^{a_3-1} \to \frac{a_1}{x_1} = \frac{a_2}{x_2} = \frac{a_3}{x_3} \quad (22)$$

We will make a replacement X – to a new variable $X_i = a_i X$. Then the optimality conditions will be fulfilled for any X. We make a substitution in the fourth equation of the system (21) equality $X_i = a_i X$ and find X:

$$Y - A(a_1 X)^{a_i}(a_2 X)^{a_2}(a_3 X)^{a_3} = 0$$

$$A(a_1 X)^{a_i}(a_2 X)^{a_2}(a_3 X)^{a_3} = Y$$

$$A {a_1}^{a_i}\ {a_2}^{a_2}\ {a_3}^{a_3}\ X^{a_1 a_2 a_3} = Y \quad (23)$$

$$X^{a_1 a_2 a_3} = \frac{Y}{A {a_1}^{a_i}\ {a_2}^{a_2}\ {a_3}^{a_3}}$$

$$X = \left(\frac{Y}{A {a_1}^{a_i}\ {a_2}^{a_2}\ {a_3}^{a_3}}\right)^{1/(a_1+a_2+a_3)}$$

Then

$$X_i = a_i X = a_i \left(\frac{Y}{A {a_1}^{a_i}\ {a_2}^{a_2}\ {a_3}^{a_3}}\right)^{1/(a_1+a_2+a_3)} \quad (24)$$

$$I_{min} = (a_1 + a_2 + a_3)\left(\frac{Y}{A {a_1}^{a_i}\ {a_2}^{a_2}\ {a_3}^{a_3}}\right)^{1/(a_1+a_2+a_3)}$$

To achieve the given resultant factor Y, the minimum required index I (sum of factors) will be equal to I_{min} (24), thus it is possible to find the minimum necessary factors of the factors X_1, X_2, X_3.

On the whole, the preliminary assumption about the level of the expansion of investment potential has been mathematically confirmed.

4 CONCLUSION

The article proposes the scientific principles of determining the need for the total volume of investment resources necessary for the formation of investment potential in a four-stage structure with the use of a three-factor production function.

The conducted studies showed that the subjects of market activity, investors, can use the proposed mathematical apparatus in order to determine the factors that affect the improvement of the investment potential of the industry, the degree of their influence, thus determining the values necessary to achieve a given level of investment potential.

The results obtained in this article should be used for further substantiation of the priority directions of the state investment policy in the construction industry and in the search of effective tools for its implementation.

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Preliminary communication

A COMPARATIVE STUDY ON COMMON POWER FLOW TECHNIQUES IN THE POWER DISTRIBUTION SYSTEM OF THE TEHRAN METRO

Mohammad GHIASI

Abstract: Overall, a power-flow study is a steady-state assessment whose goal is to specify the currents, voltages, and real and reactive flows in a power system under a given load conditions. This paper presents a comparison of common power flow techniques in the Tehran metro power distribution system at the presence of non-linear loads. Moreover, a modelling, simulation and analysis of this power distribution system is implemented with the Electrical Transient Analyser Program (ETAP) software. In this assessment, common power flow techniques including the Newton-Raphson (NR), Fast Decoupled (FD), and Accelerated Gauss-Seidel (AGS) techniques are provided and compared. The obtained results (total generation, loading, demand, system losses, and critical report of the power flow) are analysed. In this paper, we focus on the detailed assessment and monitoring by using the most modern ETAP software, which performs numerical calculations of a large integrated power system with fabulous speed and also generates output reports. The capability and effectiveness of the power flow analysis are demonstrated according to the simulation results obtained with ETAP by applying it to the power distribution system of the Tehran metro. In developing countries such as Iran, off-line modelling and simulation of power grids by a powerful software are beneficial and helpful for the best usage of the electrical energy.

Keywords: ETAP; modelling; Power Flow Assessment; simulation; Tehran metro

1 INTRODUCTION

1.1 Background

The purpose of power flow studies is to plan ahead and account for various hypothetical situations. For instance, if a transmission line is to be taken off line for maintenance, the question is whether the remaining lines in the system can handle the required loads without exceeding their rated values. Power flow is one of the most important tools utilized by electrical experts for the design, planning, control, and analysis needed to determine and specify the best operation for power distribution systems and the exchange of power between utility companies. In the past few years, electrical engineers have been dealing with power system studies by using new software tools. Recent advances in electrical engineering sciences have brought a revolution in the field of electrical engineering after the development of powerful computer-based software [1-4]. A load flow assessment method might take a long time, and hence prevent the achievement of an accurate result for a power flow solution due to continuous changes in power generation and demand. The essential data achieved from a load flow study is the magnitude and phase angle of the voltage at every feeder and bus, and the real and reactive power flowing in every line [5, 6]. Commercial power systems are usually too complex to allow handling solutions for the power flow. Large-scale digital computers have replaced analogous methods with numerical solutions. Moreover, in order for the power flow study to function, computer programs perform related calculations such as short-circuit fault assessment, stability studies with a focus on the transient and steady-state, unit commitment and economic dispatch [7]. Maintaining a high level of system security is one of the more important aspects of power systems that should be noted, as well as the economic operation of these systems [8, 9].

1.2 Literature Review

In recent years, many researchers have proposed different approaches for the analysis, simulation and modelling in power systems and metro structures. Some recently published papers and literature reviews can be found in [10-14]; the most important factors of metro tunnel safety and the importance of safety and security needed to enable the existence of more comfortable services in metro tunnel and subway stations is explained in [15]; in the reference [16], the criteria and rules for the design of a metro path are discussed; in the paper [17], the authors presented a review of a probabilistic load flow in power systems; the reference [18] deals with the analytical methodology for the assessment of a smart monitoring impact on a future electric power distribution system. In the papers [19, 20], new prediction model based on a new feature selection and hybrid prediction engine are introduced.

The Newton-Raphson (NR) power flow, with a consideration of the fuzzy load and in the presence of distributed generations in a distribution network, is presented in [21]. The paper [22] uses a new algorithm for the optimal sizing and sitting of distributed generation in a power system. The summary explanation of the nonlinear of load flow problems is described in the reference [23]. The references [24, 25] propose a novel method to deal with energy minimization; and finally in the paper [26], wavelet decomposition combined with an adaptive neuro-fuzzy inference system is used for short-term wind power forecasting. In the reference [27], by using a modified breadth-first search strategy, the improvement of a backward/forward sweep load-flow approach is presented. The goal of the paper [28] is to specify the optimal grid switching condition of minimum losses, with the precondition of keeping the stable voltages on all buses.

1.3 Motivation and Main Contribution

In this paper, the research team focuses on the effective usage of the ETAP software for the load flow assessment and modelling of the electrical power network of the Tehran metro. The results comprise large power distribution systems emanating from high voltage (H.V.), medium voltage (M.V.), and low voltage (L.V.) networks, equipment and loads; the data used for the assessment objective are in the form of one line diagrams of the complete and actual power grid of the Tehran metro starting from HVS and the power transformer at the grid up to the loads. The ratings of all components of the power system network are taken as they actually exist. Moreover, the transformers, load switch (L.S.) and circuit breakers (C.B.), conductor's cables, distribution system and DC components are also simulated according to the actual ratings by the ETAP, and this innovative concept deals with 63 kV, 20 kV, 0.75 kV and 0.4 kV network simulations with the ETAP software.

1.4 Paper Structure

The remainder of this paper is organized as follows: Section 2 introduces the fundamental theories of the proposed method. Section 3 describes a case study analysis approach to the power distribution system of the Tehran metro in detail. In Section 4, the prediction results are given. The conclusions are presented in Section 5.

2 MATERIALS AND METHOD

In this section, three common power flow methods are explained.

2.1 Bus Classifications

According to the references [29-32], the feeder bus is a point or node where one or several generators, transmission lines, and loads are connected. It can be said that generally, in every power system analysis, each feeder bus is associated with four quantities: active power (P), reactive power (Q), voltage magnitude ($|V|$), and voltage phase angle (δ). Furthermore, feeders are divided into three categories: 1) slack bus, 2) generator (PV) bus, and 3) load (PQ) bus. Those three categories are shown in Tab. 1.

Table 1 Bus classification

Type of Bus	Variables			
	P	Q	V	δ
Slack	Unknown	Unknown	Known	Known
(PV)	Known	Unknown	Known	Unknown
(PQ)	Known	Known	Unknown	Unknown

2.2 Power Flow Calculation Methods

In the last few decades, for solving load flow analysis problems, several numerical assessment methods have been proposed. It can be said that the most commonly used iterative methods are the Gauss-Seidel (GS), the Fast-Decoupled (FD), and the FD methods [5, 33]. According to the reference [5], when performing load flow assessment, the first step is to form the Y-bus admittance using the transmission line and the transformer input data. The nodal formula for a study of the power system network using the Y-bus can be given as follows:

$$I = Y_{Bus}V \tag{1}$$

The nodal formula can be expressed in a generalized form for a n bus system as follows:

$$I_i = \sum_{j=1}^{n} Y_{ij}V_j; \text{ for } i = 1, 2, 3, \dots, n \tag{2}$$

And the complex power and the current delivered to bus i are given by the following formula:

$$P_i + jQ_i = V_i I_i^* \tag{3}$$

$$I_i = \frac{P_i - jQ_i}{V_i^*} \tag{4}$$

Replacing for I_i in terms of P_i and Q_i, the following formula is given as:

$$\frac{P_i - jQ_i}{V_i^*} = V_i \sum_{j=1}^{n} Y_{ij} - \sum_{j=1}^{n} Y_{ij} V_j ; \; j \neq i \tag{5}$$

On the other hand, according to the reference [34], a complex power injection of the system is given by the following formula:

$$S_i = S_{Gi} - S_{Di} = \text{Generation} - \text{Load} \tag{6}$$

$$S_i = \sum_k^n S_{ik} \tag{7}$$

where in the Eqs. (6) and (7): k = 1, 2,…, n; i = 1, 2,…, n. Similarly, the phasor of current injections is given by the following formula:

$$I_i = I_{Gi} - I_{Di} = \sum_k^n Y_{ik} V_{ik} \tag{8}$$

$$\mathrm{S_i = V_i I_i^* = V_i \sum_k^n Y_{ik}^* V_k^*} \tag{9}$$

$$S_i = \sum_k^n |V_i||V_k| e^{j\delta ik} (G_{ik} - jB_{ik}) \tag{10}$$

where: $V_k = |V_k|e^{i\delta ik}$; $\delta_{ik} = \delta_i - \delta_k$; $Y_{ik} = G_{ik} + jB_{ik}$

Breaking down the complexity of power flow formulation into real and imaginary parts is given by the following formula:

$$S_i = P_i + jQ_i = \sum_k^n |V_i||V_k| \, e^{j\delta ik} (G_{ik} - jB_{ik}) \tag{11}$$

$$P_i = \sum_k^n |V_i||V_k| \, [G_{ik} \cos(\delta_{ik}) + B_{ik} \sin(\delta_{ik})] \tag{12}$$

$$Q_i = \sum_k^n |V_i||V_k| \, [G_{ik} \cos(\delta_{ik}) - B_{ik} \sin(\delta_{ik})] \tag{13}$$

These Eqs. (11), (12), and (13) utilize iterative techniques to solve power flow problems. Therefore, they are necessary to review the general forms of these various solution methods: NR, FD and Accelerated Gauss-Seidel (AGS) power flow.

2.3.1 Newton-Raphson Method

The NR method iteratively solves and formulates the following power flow equation:

$$\begin{vmatrix}\Delta P\\ \Delta Q\end{vmatrix} = \begin{vmatrix}J1 & J2\\ J3 & J4\end{vmatrix}\begin{vmatrix}\Delta\delta\\ \Delta V\end{vmatrix} \quad (14)$$

where in the Eq. (14), $J1$, $J2$, $J3$ and $J4$ are the Jacobean matrix elements. P and Q are the specified feeder real and reactive power mismatch vectors between the calculated value and the specified value, respectively; ΔV and $\Delta\delta$ represent the voltage magnitude of the feeder bus and angle vectors in an incremental form; besides, the elements from $J1$ to $J4$ are named Jacobean matrices [30, 32, 35, 36].

2.3.2 Fast-Decoupled Method

The FD method originated from the NR method. It takes in the fact that a small variation in the voltage magnitude of the feeder bus does not extremely change the real power at the feeder bus, and also, for a small variation in the phase angle of the feeder bus voltage, the reactive power does not vary too much. Therefore, the equation of the power flow from the NR method can be simplified into two separate decoupled sets of power formulas, which according to the references [30, 32, 35, 36] can be solved iteratively:

$$\begin{aligned}|\Delta P| &= |J1||\Delta\delta|\\ |\Delta Q| &= |J1||\Delta V|\end{aligned} \quad (15)$$

It can be said that compared to the N-R method, the FD method reduces the storage of computer memory by almost half. It also solves the power flow formulas by taking substantially less computer time than that required by the NR method, due to the fact that Jacobean matrices are constant [30, 32, 35, 36].

2.3.3 Accelerated Gauss-Seidel Method

Based on the equation of the system nodal voltage:

$$|I| = |Y_{Bus}||V| \quad (16)$$

The AGS method derives the following power flow formula and solves it iteratively:

$$|P + jQ| = |V^T||Y^*_{Bus}V^*| \quad (17)$$

where in the Eq. (17), P and Q are the specified bus real and reactive power vectors, V is the voltage vector of the feeder bus; Y_{Bus} is the admittance matrix of the system. Y^*_{Bus} and V^* are the conjugates of Y_{Bus} and V, respectively. V^T is the transpose of V [30, 32, 35, 36].

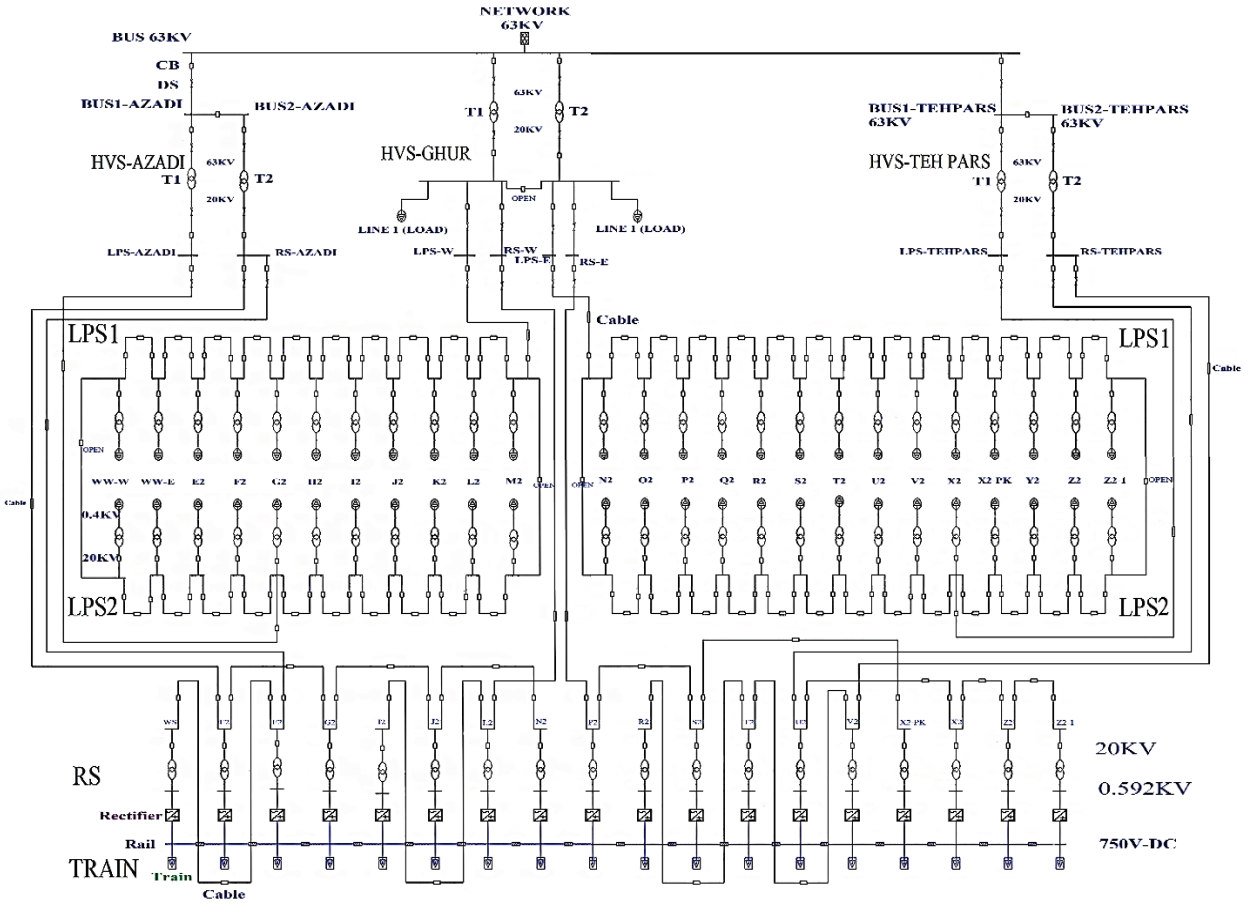

Figure 1 Single line diagram of the Tehran metro power distribution system in the form of ETAP

Table 2 LPS information data

Station	LPS	kW·h	kVAr·h	% P.F
WWW	LPS1	13210	12610	0.7233555
	LPS2	88820	58220	0.8363717
WWE	LPS1	104430	46830	0.9125093
	LPS2	79240	59440	0.8011232
E2	LPS1	134450	87650	0.8377593
	LPS2	164460	105100	0.8427737
F2	LPS1	75070	62450	0.7687251
	LPS2	79880	46860	0.8626003
G2	LPS1	82290	52870	0.8413779
	LPS2	48610	43880	0.7428379
H2	LPS1	98420	59290	0.8568776
	LPS2	65630	42300	0.8398448
I2	LPS1	70240	63610	0.7410854
	LPS2	66650	54620	0.7733361
J2	LPS1	77460	71430	0.7350218
	LPS2	50470	49840	0.7113282
K2	LPS1	81080	100250	0.6263911
	LPS2	39090	54660	0.5812381
L2	LPS1	63610	90670	0.5745531
	LPS2	85820	96680	0.6640755
M2	LPS1	104430	88290	0.7638856
	LPS2	104000	87100	0.7700215
N2	LPS1	28700	36100	0.6204821
	LPS2	123500	90100	0.8083965
O2	LPS1	55220	57500	0.6919053
	LPS2	121230	94300	0.7895626
P2	LPS1	135640	80500	0.8601678
	LPS2	51650	23300	0.9107287
Q2	LPS1	36460	27100	0.8010550
	LPS2	22470	34900	0.5412459
R2	LPS1	145280	108700	0.8007934
	LPS2	38490	24100	0.8479983
S2	LPS1	159100	114610	0.8112439
	LPS2	41300	39100	0.7278902
T2	LPS1	156100	112100	0.8118303
	LPS2	28210	20500	0.8102244
U2	LPS1	154100	115900	0.7996264
	LPS2	36000	32500	0.7432941
V2	LPS1	165500	119410	0.8111439
	LPS2	6620	8410	0.6178215
X2	LPS1	53300	26100	0.8984435
	LPS2	143610	40500	0.9626290
Y2	LPS1	143252	93292	0.8380018
	LPS2	44735	7475	0.9863348
Z2	LPS1	58049	20251	0.9446808
	LPS2	120174	54718	0.9101126
Z2-1	LPS1	24266	43813	0.4842675
	LPS2	21245	24950	0.6485155
X2-PK	LPS1	78410	36810	0.9052369
	LPS2	44420	26010	0.8629317

3 CASE STUDY

According to the reference [37], the line 2 of the Tehran metro is supplied from three high voltage substations (HVS) and consists of 154 main feeders. All HVSs in the power network of the Tehran metro comprise 63/20 kV and a gas insulated substation (GIS) type. Each station of the Tehran metro has two lighting and power substations (LPS). The LPSs supply electric power for the equipment and loads. The LPS is located at each substation platform. The rectifier substation (RS) converts AC to DC power to supply electrical energy for the traction motors of trains. Most stations on line 2 of the Tehran metro have one RS. Each RS is capable to convert 20 kV (AC) to 750 V (DC) using diode rectifiers. A single line diagram of the Tehran metro power distribution system in the form of ETAP is displayed in Fig. 1.

As shown in Fig. 1, HVSs are located at the top, LPSs and loads at the middle, and RSs and loads at the bottom. According to the monthly report (August 2017) from the Tehran metro power distribution unit, the total consumption for LPSs and RSs (active and reactive) are measured, and that informational data are presented in Tab. 2 and Tab. 3, respectively.

Table 3 RS information data

Station - RS	kW·h	kVAr·h	% P.F
WW	38020	7020	0.9834531
E2	258020	35020	0.9909234
F2	305030	51030	0.9863063
G2	365040	69030	0.9825968
I2	389050	69040	0.9846302
J2	313060	55050	0.9849100
L2	408070	72060	0.9847835
N2	291080	46070	0.9877354
P2	365090	62020	0.9858781
R2	292100	51010	0.9850876
S2	292500	47010	0.9873774
T2	222100	32030	0.9897701
U2	198020	27000	0.9901485
V2	195030	23050	0.9931157
X2	236040	30010	0.9920170
Y2	198050	51020	0.968391
Z2	206000	51030	0.9709646
Z2-1	217010	55000	0.9704049

For the implementation of this simulation, the values used to compare the three methods of load flow are shown in Tab. 4.

Table 4 The values of power flow methods

Method	Max Iteration	Precision	Accel. Factor
NR	10	0,0001	-
FD	99	0,0001	-
AGS	2000	0,00001	1,45

4 RESULTS AND ANALYSIS OF THE POWER FLOW

Tab. 5 shows the summary report of branch losses (Max. Loading) in the power distribution grid of the line 2 of the Tehran metro.

Table 5 Branch losses summary report (Max Loading)

Method	Losses Branch (Transformers, Cables)	
	kW (P)	kVAr (Q)
NR	1494.61	18168.20
FD	1494.62	18168.22
AGS	1494.61	18168.21

As it can be seen from Tab. 5, the results of all three methods are very close together.

As it can be seen, the results of these three load flow methods are almost exactly the same; hence, due to the similarity of the results in each of the three load flow simulations, the critical reports of the NR load flow are illustrated in Fig. 2 and 3 respectively. Fig. 2 shows the amount of under voltage (kV) in different distribution

transformers. Fig. 3 shows the percentage of overload on transformers. The marginal and critical voltage drop and overload standard set by utility are 2% and 5% respectively, and here they are significantly violated. The summary of the total generation, loading and demand for the maximum loading of the case study are shown in Tab. 6.

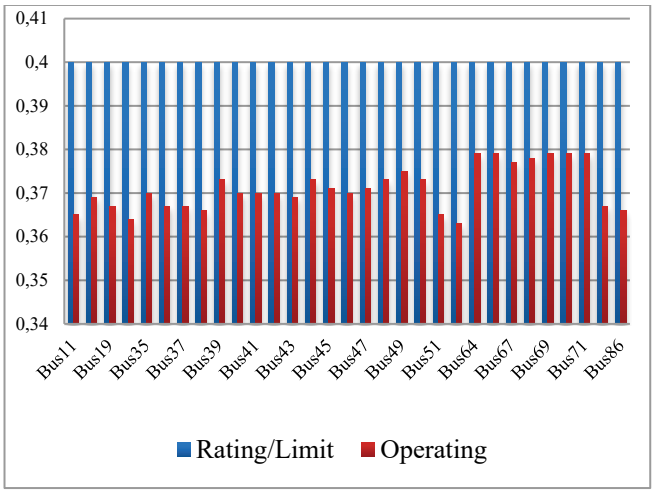

Figure 2 Voltage drop (kV) on the buses

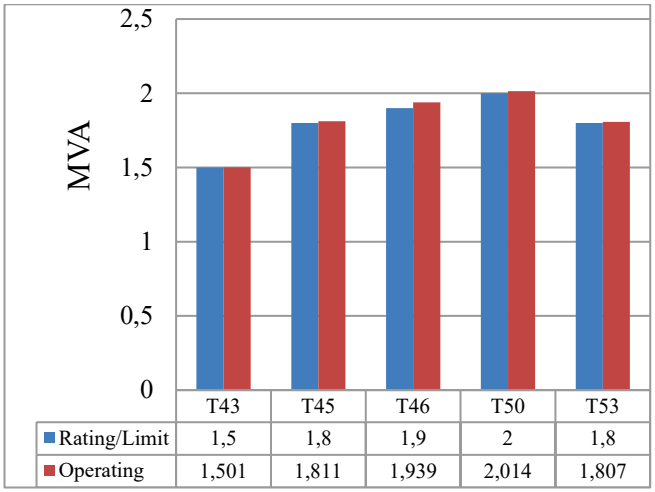

Figure 3 Overload on transformer

Table 6 Summary of total generation, loading and demand (Max. Loading)

Type	MW (P)	MVAr (Q)	MVA (S)	% P.F
Source	97.824	83.84	128.345	73.22 Lagging
Total Demand	97.824	83.084	128.345	76.22 Lagging
Total Motor Load	86.764	58.037	104.385	83.12 Lagging
Total Static load	9.566	6.878	11.782	81.19 Leading
Apparent Losses	1.495	18.168	-	-

5 CONCLUSION

In this paper, a case study of the modelling, simulation and power flow analysis of the actual power distribution system of the Tehran metro (Line 2) in the presence of non-linear loads by using the ETAP was implemented. Furthermore, a comparison of three common power flow techniques was presented. The theoretical and practical approaches of load flow have been learned, compared, and applied to solve the given tasks. The results of power flow assessment (total generation, loading, demand, and power losses) were obtained and analysed. The numerical methods of the power flow (Newton-Raphson, Fast-Decoupled, and Accelerated- Gauss-Seidel) were compared. Moreover, a power flow based simulation using the ETAP were developed to find the optimum location of the distribution system unit for a load profile improvement and the minimization of power losses in the test distribution system. By using a powerful software such as ETAP for speed performance and computational accuracy is very practical and helpful, and it also offers a better view of the power network for analysis. In a developing country such as Iran, it is highly beneficial that off-line modelling includes the active and reactive power flows, current flow in every branch, PF correction, reliability analysis, etc. of a large electrical power system. Additionally, understanding the best way of the power flow is economical, and therefore it can be a hot topic for future studies of the power distribution system.

Nomenclature

AC	Alternating current
B	Susceptance (Ω^{-1})
DC	Direct current
G	Conductance (Ω^{-1})
I	Current (A)
I^*	Conjugate of I
J	Jacobian matrix
n	Number of branch (i, k)
P	Active power (kW)
Q	Reactive power (kVAr)
PV	Generator bus
PQ	Load bus
S	Apparent power (kVA)
V	Voltage (V)
V^*	Conjugate of V
V^T	Transpose of V
Vi	Voltage at node i (V)
$\|V\|$	Voltage Magnitude
Y	Admittance (Ω^{-1})
Y_{Bus}^*	Conjugate of Y_{Bus}
i, j and k	Indices of buses
δ	Phase angle of voltage (degree, rad)
Δ	Mismatch
P.U	Per unit
kVA	Kilo volt ampere
kVAr	Kilo var

List of abbreviations

RS	Rectifier Substation
LPS	Lighting and Power Substation
HVS	High Voltage Substation
P.F	Power Factor
GIS	Gas Insulated Substation

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Subject review

A REVIEW STUDY ON ENERGY HARVESTING SYSTEMS FOR VEHICLES

Umut AKSU, Recep HALICIOGLU

Abstract: The widespread and increasing consumption of fossil-based fuels as an energy source causes a rapid decrease of these natural sources, as well as an increase of pollution in the atmosphere. Fuel oil, one of the products of fossil fuels, is today the commonly used energy source for transportation. The importance of contributing to the fuel economy and of increasing environmental consciousness have necessitated certain measures in the automotive sector, as well as in other industrial sectors. Therefore, the technological developments recently carried out in the automotive sector aim to reduce the consumption of fossil fuels, for example by recovering waste energy in vehicles. In this direction, efforts have been centered upon the development of energy harvesting systems that provide energy recovery from dynamic parts of the vehicles, such as suspensions. Moreover, the regenerative braking systems that recover some amount of kinetic energy of the vehicles slowing down have been developed and have been in use long since. In this study, research studies on providing the recovery of the vehicles' waste energy are reviewed with their comparisons.

Keywords: energy harvesting; hybrid/electrical vehicles; regenerative braking; vehicle suspension systems; vehicle vibrations

1 INTRODUCTION

Energy requirements which have increased continuously from day to day have to a considerable extent been met with fossil fuels. However, besides the environmental problems arising from the use of fossil fuels, a steady decline of fossil fuel sources directed researchers to new researching subjects such as energy-saving systems, energy recovery mechanisms and the discovery of clean energy resources. In the global framework, the highest share with the percentage of 64.5 consumption of oil and by-products belongs to the transportation sector [1]. Moreover, the transportation sector has a significant share (14 %) in the total amount of greenhouse gas emissions to the atmosphere [2]. Given these considerations, there have been considerable interests in the study of increasing energy efficiency for road vehicles such as automobiles, that have the most common usage in transport.

In this study, previous studies about the energy harvesting systems developed for vehicles are compiled and discussed in terms of their comparative and similar features.

2 ENERGY HARVESTING TECHNOLOGIES FOR VEHICLES

In vehicles, fuel efficiency is below 75 % due to various losses. A significant amount of total energy loss in the vehicle is caused by irreversibilities (thermal losses, friction losses, pump losses, incomplete combustion, etc.) that occur in the engine section. Reducing the energy losses through the engine and increasing engine efficiency are also other research interests [3-5]. For example, for an ordinary car in urban transportation, the power transferred to various parts of the vehicle and the known energy losses are given in Tab. 1 [6].

The amount of energy required for the movement and management of a car constitutes 22.5 % of the total energy consumed. This amount is the sum of the energy used to move the wheels against various road and weather resistances, along with the power used at the powertrain and other losses [6]. Considering the importance of fuel economy and energy efficiency, studies have been conducted to reduce energy losses, even for very small quantities, to the minimum at the powertrain of the vehicle. Within the scope of these studies, regenerative braking systems and energy harvesting suspension systems are the subjects of the research.

Table 1 Energy consumption distributions of an ordinary automobile in the urban transport [6]

Engine losses	**75.2 %**
- Thermal losses	63.5 %
- Pumping losses	5 %
- Combustion inefficiency	3.4 %
- Friction losses	3.3 %
Auxiliary	**2.3 %**
- Alternator	2.3 %
Power to wheels	**22.5 %**
- Vehicle inertia	5.7 %
- Aerodynamic drag	3.8 %
- Rolling resistance	3.8 %
- Torque converter	1.7 %
- Other drag	1.7 %
- Transmission	1.4 %
- Differential	1.2 %
- Others	3.2 %

By definition, energy recovery is the conversion of energy losses occurring in various stages of the processes occurring in mechanical systems that are powered by an energy source into the form of available energy through specially designed devices and re-use in the case of need. The recovered/harvested energy can be used to actuate various electrical devices such as wireless sensors converted to electrical energy in very small quantities [7].

2.1 Vehicle Suspensions and Energy Harvesting

Vibration in vehicles is an undesirable phenomenon. Besides the increase of fuel consumption, the failure of vehicle components, vibrations at the other structures and environment, deterioration of passengers' comfort and driving safety are among the known harmful effects of

vehicle vibrations [8]. Vehicle vibrations can occur when wheels pass over a structural fault or obstacle on the road and the vehicle accelerates or decelerates [9].

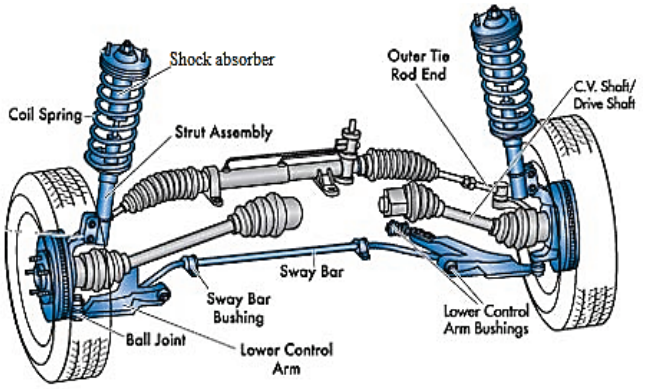

Figure 1 A typical road vehicle front suspension system [6]

Suspension systems are one of the most important vehicle components that provide the connection between the vehicle body and the wheels. The most important function of an ordinary vehicle suspension system is to provide road holding, drive control and travel comfort by damping the vertical and momentary movements (vibrations) transmitted from the wheels due to obstacles, structural obstacles, etc. during the wheel-road contact. A suspension system generally consists of a shock absorber and a spring element. The most common type of a shock absorber used today is the hydraulic absorber. In the hydraulic shock absorber, piston transfers the relative motion, which occurs in one direction (vibration), to viscous oil. In this way, the vibration energy is dissipated by the shock absorber by being converted to heat [10]. The suspension system also maintains the friction between the wheels and the road, ensures constant contact and prevents the vehicle from slipping off the road [11,12]. The front suspension system, known as independent suspension (MacPherson), and widely used in road vehicles is shown in Fig. 1 [6].

In recent years, the consciousness of contribution to the fuel economy and environmental sensitivity have accelerated the studies on the development of energy recovery systems for the automotive sector. In particular, the potential of vibration energy dissipated as heat from conventional vehicle suspension systems has attracted the attention of researchers. In the direction of the studies which have continued for 25 years on waste energy recovery from suspension systems, it has been reported that the energy potential has values ranging from 46 to 7500 W with various parameters [13]. Theoretically, the amount of vibration energy that could be recovered increases with vibration amplitude values, and the highest energy value could be obtained at the resonance frequency [14]. However, the vibration that can safely be damped by conventional suspension in vehicles is in the frequency range of 0.5 - 10 Hz [15].

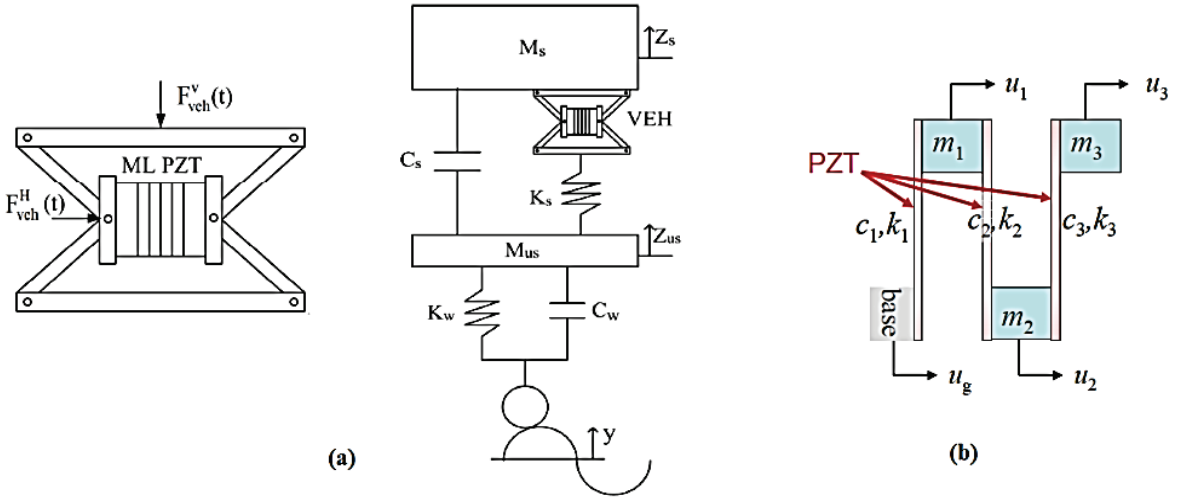

Figure 2 (a) A multilayer piezoelectric vibration energy harvesting mechanism (ML PZT VEH) [9], (b) A multi-mode vibration-based energy harvester [17]

An electromagnetic shock absorber was designed and optimized by Zuo et al. [14]. The results that were obtained from the finite element analysis with the model and the experiments performed with the 1:2 scale prototype have been seen as consistent with each other. Hadas et al. [16] designed a mechatronic system that is sensitive to energy recovery from vibrations in aviation applications. The power output of 35 mW was obtained. Hendrowati et al. [9] performed a simulation analysis by generating a 1-degree-of-freedom mathematical model of the multilayer piezoelectric vibration energy recovery system (ML PZT VEH) that they developed. The maximum 6.23 V voltage and 1.6 mW power output values were obtained from the 2-degree-of-freedom quarter car model (suspension test setup) to which the ML PZT VEH mechanism was adapted (Fig. 2(a)). Furthermore, any effect that may cause a change in the performance of vehicle suspension systems was not observed with this design. Sultoni et al. [10] designed two types of electromagnetic energy harvesting systems as linear and rotational. For these two types of systems, a comparison of the amount of energy recovered and driving comfort levels was made through a simulation analysis on a quarter car

model. As a result, a power output of 2.5×10^{-4} W was obtained for the rotary type when a power output of 90 W output was gained for the linear type. Moreover, it has been concluded that the linear type is more preferable due to the fact that it provides comfort and driving safety and a faster vibration damping than the rotary type. However, the linear type system has a more complex structure than the rotary type system. Hashimoto et al. [17] designed a specific model by using actual driving parameters to achieve a re-usable power output from the source of vibration from typical multi-mode vibrations which occur in vehicles (Fig. 2(b)). This design was made of lead zirconate titanate (PZT) plate springs connecting between three masses. Simulation analyses and experimental results for this design were founded to be consistent with each other.

Zhu et al. [18] reported that the mechanical energy of damped vibrations during driving has the potential to meet the energy needs of wireless sensors in vehicles. As the results of tests performed on roads with three different surface roughness grades classified according to the International Roughness Index (IRI), the power output values of 1.1 μW (highest 6 μW) for the class A road, 5.2 μW (highest 35 μW) for the class C road and 13.1 μW (maximum 130 μW) for the class E road were recorded. According to the power output values gained from experiments, on the road with the class E surface quality, there was the potential to meet the energy need of the wireless sensors through the designed piezoelectric energy recovery device. Moreover, they reported that the position where the energy recovery system had been installed in the vehicle was important. The highest amount of energy recovery was obtained at the rear suspension of the vehicle and also near the trunk.

Zuo et al. [13] recorded the amount of vibration energy, which could be recovered between 100–400 W, through the analyses of the mathematical model with the quarter car model and the actual driving experiments. Lafarge et al. [19] reported that the vibration energy of 0.5 mW was recovered at a speed of 30 km/h with the piezoelectric (PZT5H) energy harvesting system with the quarter car model. Shah et al. [20] gained 100 V voltage value at a speed of 10 km/h and 180 V at a speed of 20 km/h on a relatively smooth road; 160 V at a speed of 10 km/h and 320 V at a speed of 20 km/h passing over a bump with an electromagnetic energy harvester they designed. In this design, shock waves are damped by the electromagnetic field generated by natural magnets instead of damping with hydraulic oil (Fig. 3(a)). Zhang et al. [21] introduced a novel electro–hydraulic energy harvesting damper for large weighted vehicles and poor road conditions, such as off–road driving (Fig. 3(b)). First, the dynamic model was mathematically expressed. Then, the prototype of the damper was manufactured, and experiments were conducted to investigate the effectiveness of the damping characteristics and energy harvesting capability. The maximum output power of 200 W and the average of 110.6 W were obtained with the maximum excitation speed of 0.52 m/s and external load of 10 Ω. Through this design, unidirectional generator rotation realized, and thereby the energy harvesting efficiency was improved. Furthermore, the undesired temperature rise of damper oil was avoided and it even remained nearly constant through this design.

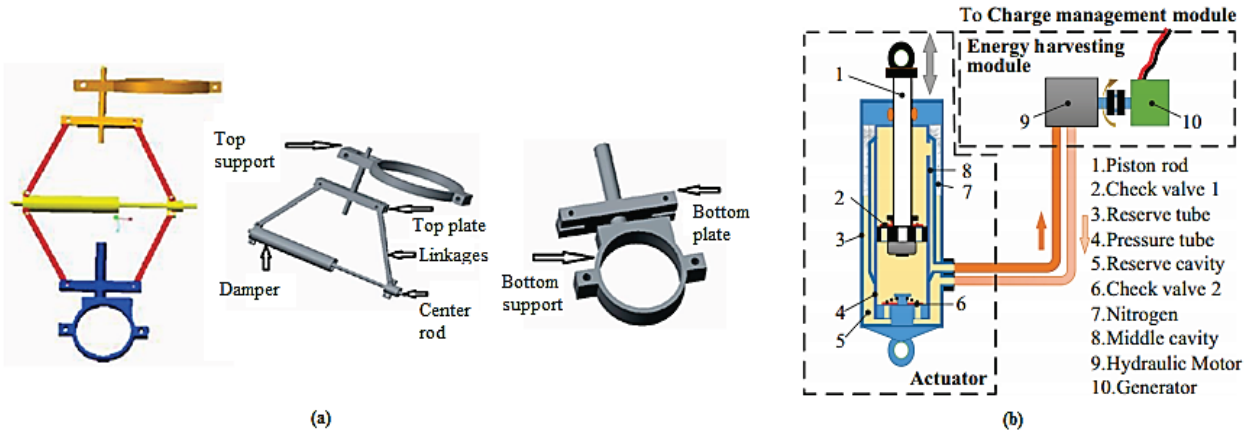

Figure 3 Designs of (a) an electro–magnetic shock absorber energy harvesting system [20] and (b) an electro–hydraulic shock absorber energy harvesting system [21]

Adly et al. [22] presented an analytical approach for suspension systems such as electromagnetic energy harvesters whose components are nonlinear due to being flexibly tunable. In this approach, the finite–difference numerical analysis method was employed. The results of the analytical approach coincided with the simulations performed. Xie et al. [23] evaluated the effectiveness of the dual–mass piezoelectric energy harvesting system that they mathematically modelled according to structural design parameters and driving conditions and the accompanying numerical simulations. They gained values of a power output up to 738 W. Demetgul et al. [24] designed a hybrid vibration energy harvesting suspension which is similar both to hydraulic and electromagnetic systems in terms of the operating principle. In the experimental studies; the power outputs of 0.25 W, 0.4 W and 0.66 W were obtained for the damping rates of 0.004 m/s, 0.0045 m/s and 0.005 m/s, respectively. As a result of simulations carried out for other hybrid energy harvesting suspension systems designed by Xie et al. [25], it was found that vibration energy was directly related to road roughness and the speed of the vehicle. With the simulations performed for this design, at a speed of 120 km/h, the power output of 40 W was harvested from the suspension system on a road with Class B surface roughness

and 140 W on the road with Class C surface roughness. Satpute et al. [26] designed the passive hybrid system (hydraulic–electromagnetic shock absorber (HESA)). They aimed to increase the amount of energy that could be harvested from the electromagnetic part by increasing the moving speed of the fluid (viscous oil) in the mechanical (damper) part. The results of the experimental and theoretical studies are compatible with each other. Through the experiments performed with the prototype which was at the actual measurements, for different vibration amplitudes, the power output values varying from 18 to 227 W were gained. Mucka [27] assessed the actual energy potential that could be recovered from the suspension systems under real driving conditions. Through an ordinary car (with nine degrees of freedom), he examined the relation between the amount of energy dissipated from suspension systems and the type of road surface, the speed of the vehicle, road roughness values and the contact type parameters between the wheel and road. Zhang et al. [28] presented an original energy recovery suspension system with a hydraulic pumping mechanism consisting of an energy storage unit and a hydraulic actuator. They defined the mathematical model of the system and studied the parameters such as different vibration frequencies and electrical loads to improve the characteristics of the damper and the energy recovery efficiency. Because of parameter optimization, the best power output value from the system was obtained as 33.4 W for each suspension. Kim et al. [29] designed a regenerative suspension combined with a linear generator. The armature part was composed of a 16-pole and 16-slot Halbach array of radial and axial permanent magnets. The linear generator was capable of gathering more than 100 W of average power and 250 W of maximum power for full–sized civilian or military vehicles. As a result of the simulation analyses, the initial model also provided the maximum power of 370.38 W and the average power of 133.26 W. They later optimized their model in terms of four parameters (tooth thickness, tooth width, radial permanent magnet thickness, and axial permanent magnet width) and provided a 57.8 % higher efficiency than that of the initial model.

2.2 Energy Harvesting by Braking (Regenerative Braking)

One of the inevitable energy losses in the vehicles is the one that that occurs with braking. When the brake is applied during the motion, the brake pads impose pressure on the wheel disc to reduce the speed or stop the vehicle. While the vehicle slows down, the kinetic energy is dissipated as heat due to friction. The amount of this transformed energy due to braking depends on how frequently braking is applied, how hard it is done and on the duration of braking.

As opposed to when driving on highways, braking in urban traffic is more frequent. Braking is often applied because of the constant stop-and-go movements in heavy traffic and low speed limits within the city. Depending on the frequency of the use of brakes in the urban traffic, up to 62.5 % of the vehicle's energy gets lost. However, in the case of completely preventing energy losses of braking and also recovering losses as useful energy, it is predicted that fuel consumption would decrease by 33 %. The amount of energy recovered by regenerative braking generally depends on the sort of the storage unit, the efficiency of the powertrain, the driving situation, and the inertia of the vehicle [30].

Basically, braking which provides energy recovery is a process of catching and storing the kinetic energy that normally would be dissipated as heat when the vehicle slows down. The regenerative system transforms this energy into its useful form and keeps it ready for immediate or later use. When regenerative braking is applied, the kinetic energy of the vehicle is transferred by the powertrain to an energy storage unit [31]. Regenerative braking systems vary according to their type of the energy storage unit and the energy conversion method. From past to present, the most–known braking systems, which provide energy regeneration, have utilized springs, flywheels, electrochemical batteries and hydraulic accumulators as storage units [30].

Studies on regenerative braking started at the end of the 1800s. The first applications were installations of spring-type regenerative braking systems on the front wheels of bikes and horse-drawn cabs. Systems in which springs are employed as energy storage units are generally run directly by human power, for example bicycles, wheelchairs, etc. The characteristics of a torsion spring used as an energy storage element are determined by the weight and speed capacity of the vehicle [32]. In the 1930s, the regenerative braking technology took part in the Baku–Tbilisi–Batumi railway line [33]. In the 1950s, the Swiss Oerlikon company developed a gyrobus, which uses flywheels as an energy storage unit [34]. In the systems that utilize flywheels as energy storage units, the kinetic energy of the slowing vehicle is transformed into rotational motion energy and is stored by the flywheel. The flywheel is connected to the propeller shaft via a gearbox. An electric generator is employed so that the energy stored in the flywheel can be used in the vehicle's movement. When the vehicle needs propulsion or acceleration, the energy stored in the flywheel is transferred to the drive shaft as torque. The energy stored in the flywheel system is directly related to the weight of the flywheel and the number of revolutions of the flywheel [30, 35]. Unlike the systems using the battery as an energy storage unit, the energy can be regenerated and stored in the flywheel even for short distances and short braking durations [36]. In the systems in which hydraulic accumulators are used as energy storage units, the energy recovered by braking is stored within a pressurized working fluid in a spherical or cylindrical vessel. The working fluid is usually nitrogen gas. When braking is applied, the engine driven by the wheels behaves as a hydraulic pump and compresses the working fluid in the accumulator. Hydraulic accumulator systems are lighter, smaller and cheaper than other systems [30].

Regenerative braking systems have become common with the development of the hybrid/electric vehicle technology. In 1967, the American Motor Vehicle Company (AMC) implemented regenerative braking system to the electric vehicle prototype, AMC Amitron. The first commercial use of the regenerative braking system is the Toyota Prius series [33]. The regenerative braking systems that are integrated into hybrid and electric vehicles utilize

electrochemical batteries as energy storage units. When the brake is applied, the electric motor acts as a generator that converts kinetic energy into electric energy and transmits it to the battery. When the vehicle needs propulsion or acceleration, the electric motor works as an engine of the vehicle, i.e. it converts the electric energy in the battery to mechanical energy and transfers it to the wheels. The general operation of regenerative braking systems is schematically shown in Fig. 4 [30, 31].

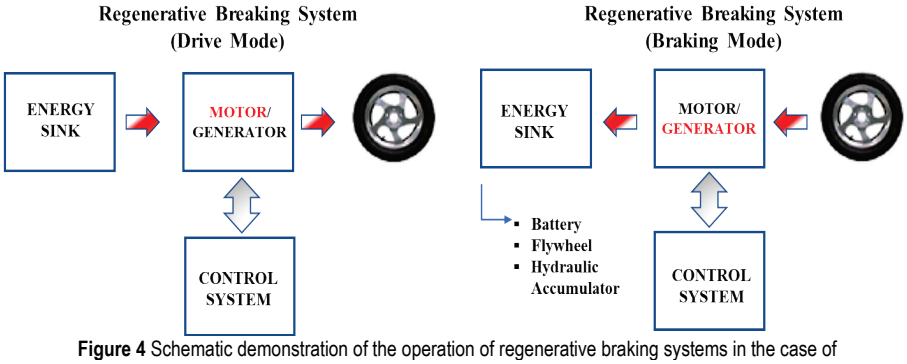

Figure 4 Schematic demonstration of the operation of regenerative braking systems in the case of (a) vehicle is in motion and (b) the braking condition [35]

Since batteries are the only power sources of electric vehicles, the efficiency of a battery directly affects the electrical vehicle's performance. Unfortunately, in real driving conditions, electrochemical batteries limit the performance of electrical vehicles due to fast discharging during acceleration or fast recharging as the braking is applied. Moreover, a battery can be fully charged within 1–3 hours. [37]. It has been experienced from real driving conditions of electric vehicles that at low speeds and short distances, it is not possible to use active recovery braking and conventional braking must also be used for a safe full stop. Furthermore, if the battery is fully charged, regenerative braking will not respond. Adding extra batteries means that there is a requirement of extra space, an increase of total weight and extra cost. The life cycle of batteries is another issue [30]. Therefore, recent studies have advocated for optimizing and managing the existing regenerative braking systems.

Gao et al. [38] proposed a regenerative braking system which would utilize a permanent magnet synchronous motor instead of the systems which use batteries as a propulsion unit. This system has a higher efficiency and a higher torque density. The simulation results of the model that were expressed mathematically have verified the system as suitable for various light electric vehicles. Considering the battery charging capacity, vehicle speed, maximum braking power of the moto, etc., Yanan [39] put forward a control strategy for the regenerative braking system. According to the study, the recovery system's efficiency reaches up to 60%. It was confirmed by some studies [37, 40] that adding an ultra–capacitor to increase the performance of regenerative braking in electric/hybrid vehicles allows the storage of 20 times more energy than that of conventional batteries. A bidirectional DC–DC converter (a hybrid energy storage system – HESS) is used to control the current into the classical system of these vehicles. Thus, the limitation of the capacity of electrical energy storage is decreased and the life of the batteries is increased. Moreover, supercapacitors make it possible to regenerate energy from braking at any speed and for any distance. Naseri et al. [41] presented a novel design by excluding the DC–DC converter unit from HESS, for improving the regenerative breaking efficiency and reducing the cost. They achieved an increase of 20 % in the efficiency compared to regenerative braking with a battery energy storage system (ESS) only. The electric vehicle's drive range was increased for about 43 km by using HESS.

3 DISCUSSION

The basic function of the suspension systems in vehicles is to dampen vibrations caused by the road and to maintain the friction between the vehicle and the road; thus, ensuring driving comfort and safety. The road-induced vibrations that occur during driving are damped by conventional hydraulic suspension systems and the mechanical energy of the vibrations is dissipated as heat. However, studies have been conducted on energy harvesting systems for the automotive sector in order to provide fuel efficiency and reduce environmental pollution in vehicles. For nearly 25 years, various energy harvesting suspension systems have been designed with the purpose of recovering the mechanical energy of vibrations instead of being dissipated as heat, transforming them into electrical energy and meeting the energy needs of such parts as various wireless sensors in vehicles. The characteristics of some studies carried out in this direction are given in Tab. 2. Commonly designed systems are: electromagnetic systems, piezoelectric systems, electrohydraulic systems and hybrid systems according to their working principles. It is claimed that mechanical (hydraulic/pneumatic) energy harvesting systems have some deficiencies compared to electromagnetic and piezoelectric energy harvesting systems. Some of them are the following:

- Parts such as pipes / hoses that provide transmission of the damping viscous fluid in the system increase the overall weight and volume of the system.

- Leaks from the transmission parts can cause the system to become completely ineffective.
- Response bandwidth of the shock absorber fluid is narrow.
- The efficiency of mechanical energy harvesting systems is relatively lower.

For these reasons, mechanical energy harvesting suspension systems are not common [12]. Piezoelectric, electrostatic and electromagnetic energy harvesting systems can convert and store the harvested energy into electricity with higher efficiency because there is no necessity to transform the energy from one type (mechanical) to another (electrical) that causes transforming losses. Moreover, the volume to be occupied by these systems is relatively small [23].

A remarkable conclusion was deduced, that the amount of vibration energy obtained from the energy recovery damping systems is directly related to the speed of the vehicle, the surface quality of the road and the rigidity of the tires; however, other parameters such as suspension stiffness, the damping degree of suspension, sprung mass and unsprung mass only affect ride comfort and safety [13].

Table 2 Studies on energy harvesting suspension systems and their characteristics

Reference	Energy Harvesting System	Method	Road Roughness	Vehicle Velocity	Power Output
Zuo et al. [13]	-	Analytical, Experimental	B,C Urban road	97 km/h	100 – 400 W
				40 km/h	58 W
Zuo et al. [14]	Linear electromagnetic system	Analytical, Experimental	Highway	-	16 – 64 W
Hadas et al. [16]	Mechatronic system	Experimental	(Laboratory)	-	7,7 – 35 mW
Hendrowati et al. [9]	Multilayered piezoelectric system	Analytical	-	43.2 km/h	1,6 mW
Sultoni et al. [10]	Rotational type electromagnetic system	Analytical	-	-	2.5×10^{-4} W
	Linear type electromagnetic system				90 W
Zhu et al. [18],	Piezoelectric system	Experimental	A	30 km/h 60 km/h	1.1 μW
			C		5.2 μW
			E		13.1 μW
Lafarge et al. [19]	Piezoelectric (PZT5H) system	Experimental	(Laboratory)	30 km/h	0.5 mW
Shah et al. [20]	Electromagnetic system	Analytical	Smooth road	10km/h	100 mV
				20 km/h	180 mV
			Speed bump	10km/h	160 mV
				20 km/h	320 mV
Zhang et. al [21]	Electro–hydraulic system	Analytical, Experimental	off–road	excitation speed of 0.52 m/s	200 W (max.) 110.6 W (avg.)
Adly et al. [22]	Electromecanical system	Analytical	-	-	4 W
Xie et al. [23]	Piezoelectric system	Analytical	-	-	738 W
Demetgul et al. [24]	Hybrid system	Experimental	(Laboratory)	-	0.25 – 0.66 W
Xie et al. [25]	Hybrid system	Analytical, Experimental	B	120 km/h	40 W
			C		140 W
Satpute et al.[26]	Hybrid system	Analytical, Experimental	-	-	18 – 227 W
Zhang et al. [28]	Hydraulic system	Analytical	uneven	-	33.4 W / per suspension
Kim et al. [29]	Electromagnetic system	Analytical (initial)	Road surface frequency of 10 Hz	-	370.38 W (max.) 133.26 W (avg.)
		Analytical (optimized)			586.43 W (max.) 214.98 (avg.)

Another energy recovery method is the use of regenerative braking systems. Regenerative braking is a process that catches and converts the slowing down vehicle's kinetic energy which is normally dissipated as heat in the case of braking and the process stores it as useful energy (electric energy). The amount of energy recovered by regenerative braking generally depends on the sort of the storage unit, the efficiency of the powertrain, driving conditions, and the inertia of the vehicle. Regenerative braking systems vary according to their type of the energy storage unit and energy conversion method. Energy storage units that have been utilized are springs, flywheels, electrochemical batteries and hydraulic accumulators. Among all of them, the most common and updated regenerative braking system is the one that utilizes electrochemical batteries and is currently used in hybrid and electric vehicles.

Since they are the only power source of electric vehicles, the total efficiency of regenerative braking systems and the performance of the vehicle depend on batteries. However, batteries have issues that limit the performance of the whole system such as an unsatisfying charging capacity and charging ratio, lifetime, energy transfer ratio, etc. In real driving conditions, electrochemical batteries limit the performance of electrical vehicles due to their fast discharging during acceleration or fast recharging as braking is applied. For low speeds and short distances, it is not

possible to use active recovery braking; therefore, conventional braking must also be used for a safe full stop.

Recent studies have dealt with eliminating the disadvantages of regenerative braking. A common method is constituting a system that employs an energy storage unit called "supercapacitors", an auxiliary to classic batteries. Supercapacitors provide many advantages such as charging in a short time, wide operating temperature range, extended run time and safety, having high power density, more efficient regenerative braking and improving vehicle acceleration [41]. However, supercapacitors have the highest cost per kWh compared to batteries or flywheel. Therefore, a specific control strategy is needed in order to use supercapacitors efficiently. Furthermore, supercapacitors contain insulator fluids which are flammable and toxic and hazardous failure modes occur if supercapacitors are subjected to overvoltage [42].

The flywheel, as another energy storage unit, can take part in regenerative braking systems. During the energy harvesting process, the losses can be avoided due to the fact that the harvested mechanical energy is transmitted without any transformation to another energy form. Thus, a flywheel has a better efficiency compared to a battery. Because they have higher power density, flywheels can deliver energy at a high rate. The operation temperature range of flywheels is wider and the operation life is longer than that of batteries. It was also concluded that flywheels are not as detrimental as batteries. Flywheels have limitations along with their advantages. Flywheels have a higher cost per kWh compared to batteries. Because they are a mechanical device, safety concerns must be resolved for any moving parts, bearing failures, etc. [42]

General properties of regenerative braking systems and expectations are summarized in Tab. 3.

Table 3 Comparison of the general characteristics of the regenerative braking system

Features of an ideal regenerative braking system [30]	Advantages of regenerative braking systems [43]	Deficiencies of regenerative braking systems [43]
- High efficiency of energy conversion	- Decrease in CO_2 emissions	- Increase in vehicle weight, increase in required volume
- High capacity energy storage per vehicle weight and volume	- Contribution to the fuel economy	- Increase in the number of systems in the vehicle, resulting in complexity
- Braking end kinetic energy can be stored with a minimum loss and delay	- Outstanding performance	- Increase in cost
- Minimal loss and delay of kinetic energy storage for a wide vehicle speed and wheel torque range	- Reduction of motor wears	- Noise due to the structure and operation of the system
- Easy transfer of energy from the regenerative system	- Reduction of braking system wears	- Unexpected failures in the system
- A non-complicated system	- Smaller components	- Dimensional constraints
- High power ratio to allow large quantities of energy to be transferred in a short time		- Extra system maintenance requirement

4 CONCLUSIONS

In today's world, energy and environment are the most crucial matters. The widespread and increasing consumption of fossil-based fuels as an energy source causes a rapid decrease of these sources and an increase of pollution in the atmosphere. This situation has raised awareness about the importance of contributing to the fuel economy and environmental consciousness. Therefore, some measures had to be taken in many industrial sectors. One of these sectors is the automotive sector, which has a big amount of energy consumption, and also a big potential for energy saving.

In this context, research studies have been made for detecting the energy losses that occur during the driving of vehicles and consequently for the reduction of these losses to the possible lowest level. Regaining of energy losses has also been researched. In this study, the previous studies related to energy regaining (harvesting) methods and systems in vehicles were compiled and discussed. Today, the most common of these methods are the vibration energy harvesting via suspension systems and kinetic energy regeneration via braking systems.

Several designs of energy harvesting suspension systems have been presented and optimized in order to ensure a better performance for different applications for the past 25 years. Through various energy harvesting suspension systems that have been designed, the mechanical energy of road-induced vehicle vibrations has been successfully recovered in varying quantities. Moreover, regenerative braking has existed for over 100 years and has already been available and applied to hybrid and electric vehicles commercially. However, both the energy harvesting suspension systems and regenerative braking technology is still under continuous development.

It can be concluded through studies that both energy harvesting methods have limitations such as total weight increases, extra space requirements, efficiency losses, costs, etc. In this respect, optimizations continue for more light weighted designs with choosing the more suitable material selection and dimensional designs. For regenerative suspensions, instead of mechanical weighted systems (hydraulic and pneumatic systems), the choice of electronic (electromagnetic/piezoelectric) component weighted systems is more favorable in terms of lightness, relatively less occupied volume, and efficiency in converting mechanical energy to electrical energy. Theoretically, the highest vibration energy recovery is provided in the resonance case. Thus, more energy can be harvested by increasing the natural frequency bandwidth of energy recovery suspension systems.

In regenerative braking systems, the type of energy storage units plays a decisive role. There are four energy storage units: electrochemical batteries, springs, flywheels

and hydraulic accumulators. Today, the most common regenerative braking system is the one that utilizes electrochemical cells. However, batteries also have shortages such as the charging capacity, energy transfer rate and life cycle which limit the electric/hybrid cars' performance. Recent studies have been improved by using supercapacitors because they fill this gap. Flywheels are also a prominent choice for hybrid vehicles due to their high energy transmitting rate.

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Subject review

INTERNAL VERIFICATION OF COATING QUALITY IN CONFORMITY WITH THE REQUIREMENTS OF THE EN 1090 STANDARD

Marko HORVAT, Dunja SRPAK, Veljko KONDIĆ, Igor PUS

Abstract: The requirements for the quality of protection on metal structures in terms of durability, reliability and efficiency require from the manufacturer to define certain procedures and verification of anticorrosion protection activities. Today, the criteria used to evaluate the success of the protection and the general quality of the structure are the criteria listed in the EN 1090 standard and in the compatible standards related to the realization and protection of metal structures. The article briefly describes the basis of the requirements of the standard, the eligibility criteria for the protection of structures and it also gives a practical example of the verification process through preparation, implementation and control.

Keywords: EN 1090; materials; metal protection; metal structures

1 INTRODUCTION

The quality of protection on metal structures in terms of durability, reliability and efficiency and the verification of anticorrosion protection activities are widely studied in scientific papers. Thereby, different coatings are researched, such as the polyetheramide (PEtA) coatings on carbon steel in [1], ecologically acceptable waterborne and multi-layered coatings in [2], or different super-hydrophobic coating systems obtained by different preparation technologies in [3]. In [4], authors demonstrate the use of different concentrations of 8-hydroxyquinoline (8-HQ) in epoxy coatings in order to detect the early stages of corrosion on metal surfaces. The anti-graffiti properties of a polyurethane organic coating are studied in [5], while the protection of buried metallic structures against corrosion by using coatings combined with cathodic protection is researched in [6]. The long-term efficacy and performance of protective coatings are tested in [7], using the wet and dry cycles of accelerated weathering and corrosion test protocols.

At the beginning of this research, the assumption was that the internal quality verification of coatings on structure materials depends mostly on the characteristics of the coating quality, surface preparation and application technology. These factors are essential for the compliance with the requirements of the EN 1090 and the related norms.

This paper is organized as follows. First, a general description of important factors influencing the quality of metal protection is given, as well as the technology of metal protection by organic coatings and certain guidance for the selection of effective organic coatings. In the next section, the procedure of internal verification implementation is described. Furthermore, the results of internal quality verification on a three-component coating system are presented. Finally, the most important conclusions are given at the end of the paper.

2 PROTECTION OF METAL AGAINST CORROSION

The application of the EN 1090 standard is related to the requirements for the conformity assessment of structural components for the construction of steel (and aluminum) structures and it covers all constituent parts or elements that can have an important impact on the construction (construction object). It defines the quality requirements that need to be met by the manufacturer, in all segments of its emergence: design, manufacture and testing.

As an important segment in the production of steel structures, the procedures related to the anticorrosion protection technology are specifically prescribed and described in Chapter 10 of this Standard, as well as all relevant standards used in the implementation of protection. Complying with the prescribed procedures is important for guaranteeing a satisfactory anticorrosion protection performance and the certification of the system of factory control. A similar verification (internal or external) is carried out on other key parts of the manufacturing process: cutting, drilling, mechanical joining, etc.

2.1 General View of Metal Protection

The corrosion of metals can be prevented by inhibiting (by preventing media aggression), by shifting the potential of local anodes in a negative sense (cathodic protection), by passivating the metal surface (anodic protection), and the most often method in practice is the separation of the metal surface from aggressive media by coating. In aggressive media and at higher temperatures, metals are required to be coated with noble metals by the diffusion method. Where less protection is required, it is sufficient to oxidize, chrome or phosphatize the metal surface. At low temperatures and with no mechanical load on the surface, organic coatings provide good protection.

2.2 The Purpose of Organic Coatings in the Metal Protection System

Most metal surfaces found on constructions and industrial structures are today generally protected by coating with certain organic materials, which can be:

- coating based on oil-paints and lacquers,
- coatings of cellulose ester lacquer,

- bituminous coatings and linings and
- coatings made from synthetic plastic resin and vinyl polymerisers.

The purpose of organic coatings is primarily to protect metallic surfaces from corrosion processes, but also to give a better appearance of the construction and plant. Apart from corrosion resistance, these coatings should include certain hardness, elasticity, impact resistance, friction resistance, mechanical strength, thermal stability, water- and steam-impermeability, longevity, etc.

One of the most important features of organic coatings is their duration. Although it depends on the characteristics of metal that is to be protected, of surface roughness, coating composition and outdoor atmosphere, very important is the procedure of applying the coating [8].

2.3 Technology of Metal Protection by Organic Coatings

Anticorrosion coating in multiple layers with different features is preferred in order to achieve a successful and complete protection of the construction or plant. Furthermore, it is important to know the technology of applying a particular coating to ensure that the coating material will meet all the requirements expected on a metal surface or at least part of them.

The technological coating application process on the metal surface comprises [9]:

1. the preparation of the metal surface – cleaning and conditioning the surface state,
2. applying of coating materials and
3. finishing (drying / hardening of the coating).

If the technological process is not carried out properly, the desired protective effect cannot be achieved even if the optimum coating system is chosen [9].

The degrees of surface preparation and metal cleaning, as well as the appearance of the surface prior and after the preparation are defined by corresponding standards [10]. For the practical implementation of this technological process, it is necessary to have adequate equipment, knowledge and quality assurance.

Coating agents can be applied on the prepared metal surface by brushes, blades, rollers or by immersing, spraying and electrophoresis.

The base coating as the most important coating layer for preventing corrosion should be capillary active to penetrate into all pores on the metal surface it protects. Additionally, high adhesion to metal, protrusion resistance and non-porousness are required. The task of covering coatings is to ensure the quality of the basic coating from mechanical and atmospheric impacts and chemical destruction.

Therefore, an important parameter in protecting metal surfaces of the construction is coating thickness. Furthermore, drying time (t) is very important and depending on the thickness of the coating (d), it can be calculated by using (1):

$$t = C \cdot a^d , \tag{1}$$

where C and a are the constant values, but the value of a is always greater than one.

2.4 Selection of Effective Organic Coatings

The selection of effective corrosion protection coatings requires the consideration of a wide range of influencing factors to ensure an optimal economic and technical solution. The most important factors to be analyzed are [10]:

- the corrosivity of the environment,
- the type of surface to be protected against corrosion,
- the durability of the coating system,
- coating application technology.

2.4.1 Corrosion of the Environment

The corrosivity of the environment encompasses the conditions to which the metal structure will be exposed during the exploitation, such as: moisture and temperature, the presence of UV radiation, exposure to chemical agents and mechanical damage (stroke, abrasion, etc.).

The international standard ISO 12944 provides a classification of corrosion for atmospheric conditions, soil and water, with the explanations about the meaning of these categories from very low and low to high and very high.

2.4.2 Type of the Protected Surface

When choosing a coating system, it is important to know the materials which the construction is made of, because that determines the degree of surface preparation, the coating material and the overall thickness of the film.

2.4.3 Durability of the Coating System

The durability of the coating system implies a period from the moment of application of the first coating to the moment of first maintenance. The standard ISO 12944 specifies three time periods that categorize the durability of the coating system as L – low (2 to 5 years), M – medium (5 to 15 years) and H – high (more than 15 years).

2.4.4 Technology and Dynamics of the Application Process

The coating system on the constructions has to be applied according to the technological process of realization. The coating application technology must take into account the surface preparation time and drying time relative to the air temperature and humidity, as well as the intervals between applying the different layers of coatings.

3 IMPLEMENTATION OF THE INTERNAL VERIFICATION OF THE COATING QUALITY

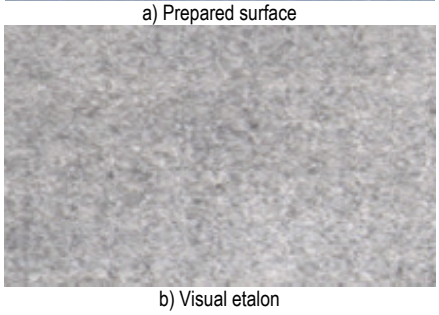
The task of internal verification is to prove the ability to implement technology according to the specific requirements

of a particular standard (or group of norms). The results of the verification of the process (technology) guarantee the quality of the works to both the contractor and investor, when performed according to the rules of the profession. The contractor can also use the resulting qualitative and quantitative data to improve the implementation of a certain technology.

The internal verification of the coating quality according to the EN 1090 norm was carried out on test specimens with the dimensions of 250 × 150 × 4 mm (material S355J2 + N). The three-component system (zinc epoxy base NA + epoxy NA + polyurethane BO) was applied according to the relevant norms and guidelines of the color manufactures (surface preparation, application conditions, minimum dry film thickness, measurement method). The expected protection system is categorized as C3-H.

Surface preparation is performed by sandblasting (quartz sand), in Sa 2.5 quality (very thorough abrasive blast cleaning) as defined by the EN ISO 8501 norm. Surface preparation control (cleaning and roughness assurance) is provided through the visual control of purity (according to visual etalons – photographs in the EN 8501 norm) as shown in Fig. 1 and by roughness measurement. Measurement was carried out in 10 points and the results are given in Fig. 2. The expected roughness is at least 40 μm (R_Z = 40 μm).

a) Prepared surface



b) Visual etalon

Figure 1 The view of the surface after sandblasting

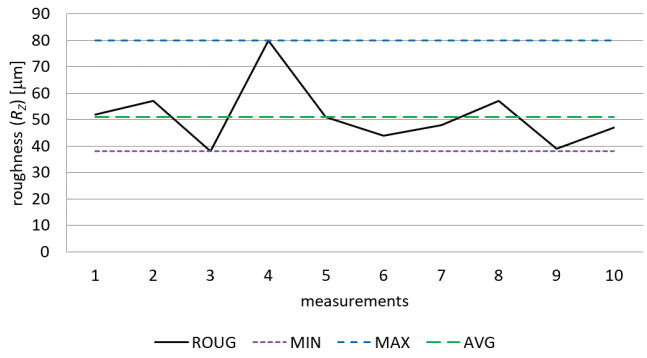


Figure 2 Surface roughness measurement results

CINK-EPOXY solvent-based primer is applied as a first coat on the prepared surface (cleansing + roughness), performed according to the rules of the profession and the recommendations of the paint manufacturer. Fig. 3 shows the appearance after applying the first layer of coating and Fig. 4 shows the results of dry film thickness measurements. As recommended by the manufacturer, the expected value of dry film thickness after the first coat for this three-component system is 40 μm.

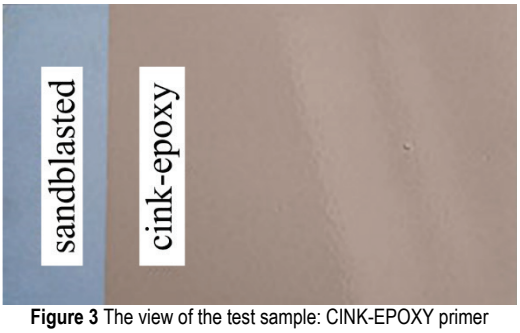


Figure 3 The view of the test sample: CINK-EPOXY primer

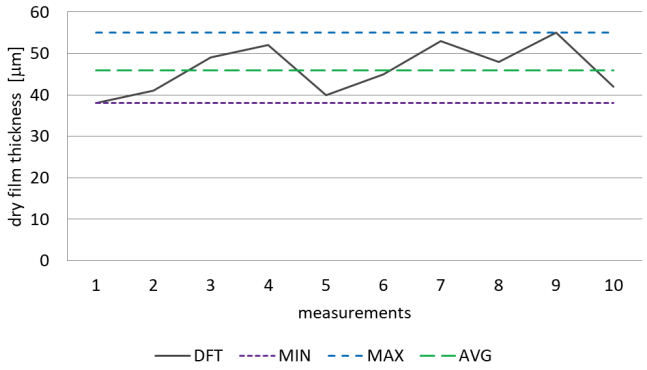


Figure 4 Dry film thickness measurement - CINK-EPOXY primer

The second component of this coating system is the EPOXY coating, also solvent-based. The coating was performed under the same conditions as the first layer, and Fig. 5 and 6 show the results. As recommended by the manufacturer, the expected value of the dry film thickness of the interlayer is 80 μm and the total value is 120 μm.

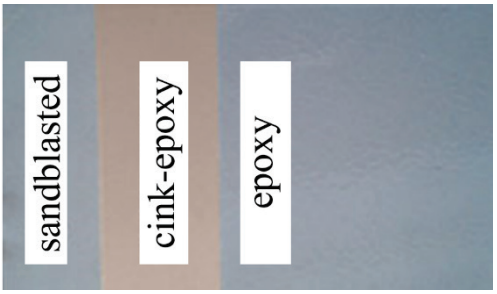


Figure 5 The view of the test sample: CINK-EPOXY primer + EPOXY

The anticorrosion protection system ends with a POLIURETHANE solvent-based coating. The recommended dry film thickness is 60 μm (total thickness is 180 μm). Fig. 7 shows a test plate with a final layer and Fig.

8 the results of dry layer thickness measurement after a three-component anticorrosion protection.

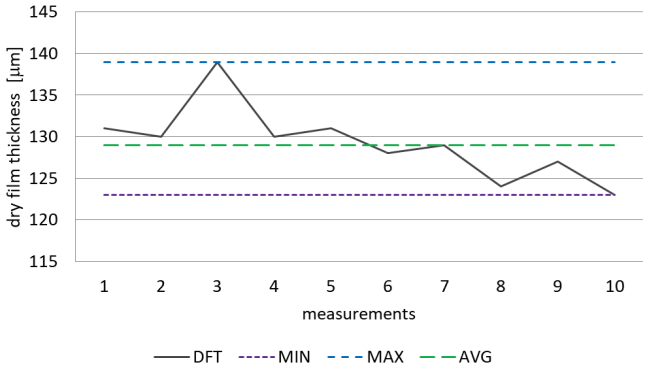


Figure 6 Dry film thickness measurement – CINK-EPOXY primer + EPOXY

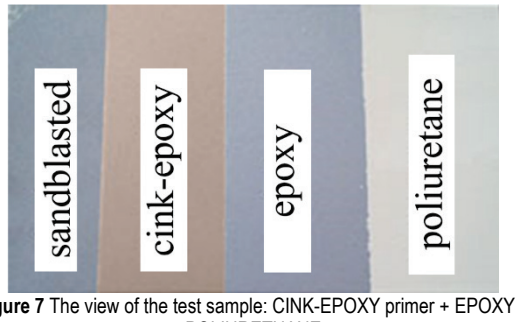


Figure 7 The view of the test sample: CINK-EPOXY primer + EPOXY + POLIURETHANE

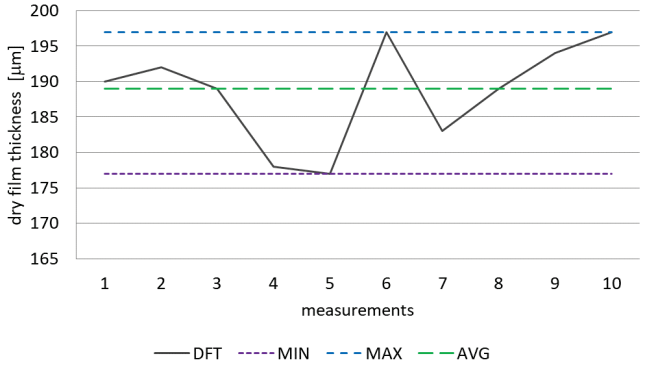


Figure 8 Dry film thickness measurement – CINK-EPOXY primer + EPOXY + POLIURETHANE

The test results (roughness and dry film thickness) confirm the expected results in accordance with the relevant norms and recommendations of the manufacturer of anticorrosion protection products. The results obtained by measuring are within the expected values and within the tolerance limits recommended by the standard. This confirms the successful verification of the anticorrosion protection technology and quality assurance in the future application of the three-component anticorrosion protection system on steel structures.

4 CONCLUSION

By entering the EU, Croatia has adopted many regulations and standards, as well as the standard for the manufacture of steel and aluminum consoles, EN 1090. This standard defines the quality requirements that the manufacturer must meet when designing, producing and testing steel and aluminum structures and components parts. Each of the aforementioned segments has to be proven through some form of documented information (record, operating instructions, verification of the procedure, etc.).

The importance of anticorrosion protection, as well as all related activities, is highlighted in EN 1090 through a separate chapter, along with a description of the basic requirements and implementation criteria, with particular emphasis on all current and relevant standards that apply to the preparation, implementation and quality control of the anticorrosive protection. This paper presents an example of the verification of the quality of anticorrosion protection by internal procedure – examination. Verification was carried out on the test sample with the standard color system (2 + 1) and with a simple way of controlling the quality of the finished works as it is usually the most commonly used for the protection of steel structures. This type of verification serves to the manufacturer as a confirmation of the performance of the protection technology (as required by the relevant documents) and reduces the possibility of errors occurring during the repetition of this and similar processes in the past. Similar verification (internal or independent) is carried out for other processes within the production (e.g. drilling, mechanical tightening, cutting, etc.), all for making the construction of the EN 1090 standard.

Note: This research was partially presented, as a poster, at the International Conference MATRIB 2017 (29 June – 2 July 2017, Vela Luka, Croatia).

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Professional paper

PAST CENTURIES INDUSTRIAL ARCHITECTURE RENOVATION METHODS

Tatiana ZHYDKOVA, Svetlana CHEPURNA, Olga POPOVA, Petr CHABANENKO

Abstract: The problems of exploitation of industrial territories located in big city centers and their impact on architectural and space urban composition have been investigated in the paper. The question of refurbishing former industrial territories to residential or social purposes has been examined. The examples of industrial territories use in other countries as well as in Kyiv and Kharkiv have been shown. The term loft has been defined in the article for industrial buildings converted to residential purpose by preserving industrial design elements or new buildings in an industrial style including those that combine residential function with professional or social.

Keywords: flour mill; "industrial" architecture landmarks; "industrial" enterprises; loft; physical conditions; renovation

1 INTRODUCTION

Industrial territories are one of the basic, system-forming elements in the structure of the city, shaping it as a socio-economic development, as well as architectural and artistic appearance. Industrial and other production facilities built in cities are usually located far from the centers of urban settlements. But as the city grew, its economic and social functions expanded, most of the enterprises were in the historical center and the central planning area of the city. As a result, industrial buildings gradually became an important part of the architecture.

Refurbishment of industrial territories as well as reconstruction of separate industrial objects is not only an economic problem, but also an architectural one. Fundamental industrial buildings have significant impact on architectural appearance of the city. Unsatisfactory physical characteristics of urban environment objects and their functional incompatibility reduce social effectiveness of city centers requiring active professional interference, particularly into the process of spatial environment formation of historically valuable city spaces previously actively exploited. De-industrialization that became a global phenomenon in the middle of the last century can be fully observed in Ukraine nowadays. On the territory of the cities that were industrial centers in the previous centuries, today, you can find areas of land previously owned by former industrial enterprises. Although some areas have been already used for other purposes, most of them are still in town-planning reserve.

For former industrial objects, one of the most effective ways to move to a qualitatively new level is restructuring.

Such an economically grounded solution will save the structures of existing buildings, bring former industrial buildings in line with current international standards and preserve the unique architectural appearance of the building. In this case, the restructuring of such buildings is becoming an optimal means for the conversion of the existing base to the implementation of fundamentally new functions.

2 THE MAIN STATEMENTS OF THE ARTICLE

Special attention should be paid to the areas in city centers, as their location is a problem in itself. Former industrial territories are often neglected and if this problem is not paid due attention to, there is a risk of disappearance of unique objects of industrial architecture of the 19th century [8].

Most often industrial enterprises occupy large areas in central districts of big cities. Most of the area cannot be used for its initial purposes. High price of renting premises in city centers make things even worse.

Reconstruction of industrial premises located in historic environment requires a specific approach. Historic building is a concentration of multiple functions and architectural forms. Therefore, the clash between the old and new is becoming even stronger in this environment along with the acceleration of historic process. Demolition is considered as a last resort when we talk about reconstruction of industrial buildings and it is not justified technically or economically.

Many foreign architectural publications show close attention to reuse of industrial buildings. They emphasize comprehensive solutions for industrial territories with objects adjacent to city centers and impact of industrial objects on architectural and spatial composition of cities.

In recent Western architectural practice, you can find more and more examples when industrial premises are used as fundamental elements of urban environment. As a rule, they are architectural spaces functioning as special purpose parks created by renovating neglected industrial or municipal zones.

In Western Europe, renovation, or restoration of urban environment to be fit for human habitation, has been actively pursued since the middle of the past century along with the beginning of the post-industrial period. Territories of former plants and factories have been converted into residential and public spaces. Industrial premises have been modified into other types of buildings, in particular, residential lofts.

It must be noted that first lofts appeared as art galleries and workshops in the 1940s of the 20th century in Soho, an industrial district of Manhattan, where textile factories were located. Very soon, people understood the benefits of such

premises giving them the status of prestigious residential properties and Soho turned into a bohemian district [1].

The pillars of loft, such as high walls, big windows, space that allows you to customize accommodation have been quickly implemented in new buildings construction process. Today the term loft refers to the industrial buildings converted into residential premises while preserving the elements of industrial design or new buildings in an industrial style including those that combine residential purpose with social [2].

In the 1960s, the fashion for loft crossed the ocean and began to spread from the USA to Great Britain, Germany, the Netherlands and other countries that had favorable environment for appearance and development of this concept.

The loft culture is becoming increasingly popular in Ukraine. The definition loft refers to premises of former industrial objects, factories, plants and research institutes converted and reconstructed for residential and sociocultural purposes. Most of former industrial premises are being modified into commercial and office buildings.

Refurbishment of industrial areas to clubs, galleries and art centers has become one of the recent cultural and social trends in Kyiv. On the territory of Kyiv glass package factory, now you can find 'G13 Project Studio'. It is a place for creativity, family vacation, concerts, and fun parties. The Studio consists of several zones that have been transformed, united and separated. The main halls are designed for photo and video shooting as well as for presentations, negotiations, press-conferences, seminars and much more [3].

Ukrainian popular singers Jamala and Tina Karol filmed videos for their songs there. This new location appeared to be in demand as art space, too. Thus, the congress of the Assembly of cultural life representatives, which was attended by more than one thousand people in two days, took place there. During the warm season, a summer terrace is a place for concerts, master-classes, discos.

Another example is 'Art-Zavod Platforma' located near the metro station 'Lisova'. It is the largest Ukrainian experiment in conversion of inactive industrial zones. The group of companies have completely reconstructed the trade space and a new format food market 'Bazar' appeared. In just one year, 'Art-Zavod Platforma' hosted more than 40 festivals, a large number of conferences, workshops, exhibitions, concerts, etc. 'Art-Zavod Platforma' is a unique space with permanent comfortable business and creativity cluster. It is the first project of this type in Ukraine. By developing the infrastructure of the space, the creative cluster intends to contribute to innovation development, not just in Kyiv, but also in the entire country. Human capital is the main value for them and they invite all creative and proactive people to their comfort space to collaborate, study, develop and exchange views [4].

Examples of successful industrial zones and buildings renovation can be found in Kharkiv, too: trade mall at Moskovsky Avenue, aqua park 'Jungli', shopping and entertainment center 'Frantsuzsky Bulvar', etc. Recently, in Kharkiv loft premises have begun to appear, too. The first project in this style is 'Fabrika' space.

'Fabrika' is located in the building constructed in 1933 and initially intended for crops sorting and storage. For many years, the premises of the former factory 'Soyuzsortsemovosch' had not been heated and bats became the only guests visiting them. In 1947, the building was reconstructed for the first time, and in 2015 for the second. It has been converted to a nice place for meeting friends and business partners, work and leisure, lectures, conferences and seminars [5].

The most interesting renovation project in Kharkiv is 'Art-Zavod Mekhanika' on the territory of the former plant named after V. A. Malyshev. 'Art-Zavod Mekhanika' is a transformation of the industrial territory into a cultural and creative location by preserving old appliances and constructions, keeping surroundings and a spirit of forgotten days.

All the territory is divided into four lines:

- Open space with green area, shops and bars, a summer cinema and theater stage, a petting swimming pool and a festival zone;
- Urban park, sports facilities, Extreme Park;
- Concert hall and Art Hall for exhibitions, seminars and conferences;
- Hostel to live on the territory, offices to work there, theater and art schools, IT schools, a beauty salon, clothing and food stores, creative and advertising workshops [6].

The problem of former industrial enterprises renovation is a subject of students' research work. This investigation is aimed at adopting objects of industrial architecture of the 19th-20th centuries in modern urban environment. The research has been carried out for several semesters, and the results have been used as the basis for coursework, diploma and master's theses. Investigations on historical backgrounds, functionality, planning characteristics and methods of industrial landmarks renovation methods are emphasized. Future architects, the undergraduates of Architecture and Constructions departments, together with students of Urban Construction and Environment department have been engaged in the research.

We must add several words about the uniqueness of Urban Construction and Environment specialty, which is an intermediate link between architects and constructors. Many foreign higher education institutions have it as a separate specialty that combines features of architects and constructors. Former name 'urban engineer' completely corresponds to the essence of the profession. Our students are as creative as architects are, and at the same time, they have profound knowledge and skills of construction process. That is why graduates are engaged in all the spheres of urban environment. Every year the results of Olympiads, competitions, international and local rewards confirm the high level of expertise. Participation in competitions enables students to present their works to the public.

For example, one student of Urban Construction and Environment specialty devoted her master's thesis to the methods of industrial areas renovation. The project of an old mill renovation has been presented within the master's thesis

investigation. Located on the riverbank in the historic center of Kharkiv, the object has convenient transportation and is surrounded with architectural monuments and other tourist attractions.

The four-story dark red-brick building with white inserts and a chimney from the rear which was initially designed as the first power station in Kharkiv and later converted to the mill is neglected now (Fig. 1). You will hardly find much data on the old flour mill on the riverbank. It was a large-scale enterprise but lack of funds led it to destruction. Several years ago, the process of conversion to a loft had begun, but shortage of funds stopped it and the building was put on a sale.

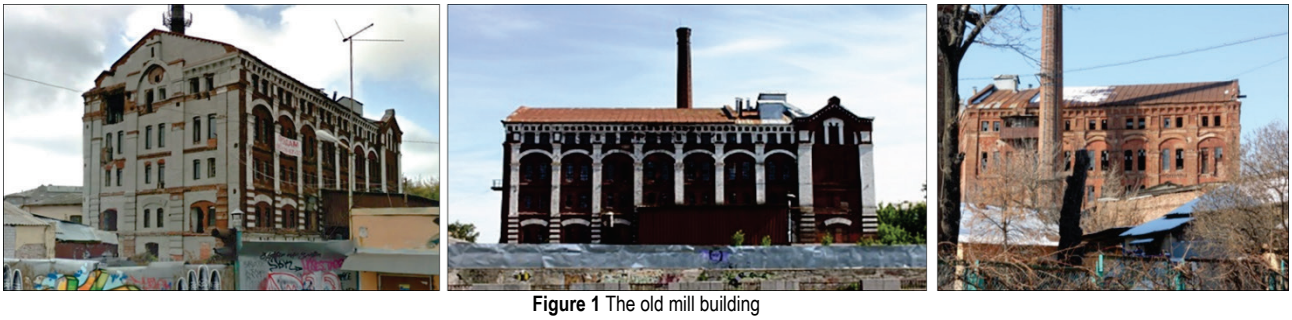

Figure 1 The old mill building

The embankment part between two bridges 'Kharkivs'ky' and 'Horbaty' had the name Dvorians'ka before the revolution, in Soviet times up to 1989 was named after Zhdanov. You can find several architectural landmarks here, such as the first private men's Lyceum named after V.F. Davydenko, which was built in 1911 by the project of architect Y.S. Tsaune. Now it is a school number 30.

Location and architectural attractiveness of the building, necessity to protect it as an industrial architecture landmark have defined such solutions as: the façade renovation, constructions physical conditions restoration, the object renovation for its second birth.

The evaluation of physical conditions has shown that the wear level in general indicators is bordering on critical – 56.7%. At the same time, the condition of the main constructions is satisfactory and they can be restored. Maximum preservation of the building exterior and its functionality change have been suggested in the project (Fig. 2).

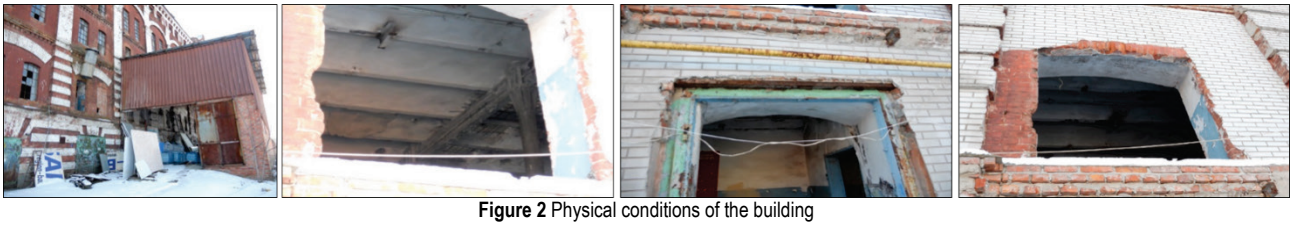

Figure 2 Physical conditions of the building

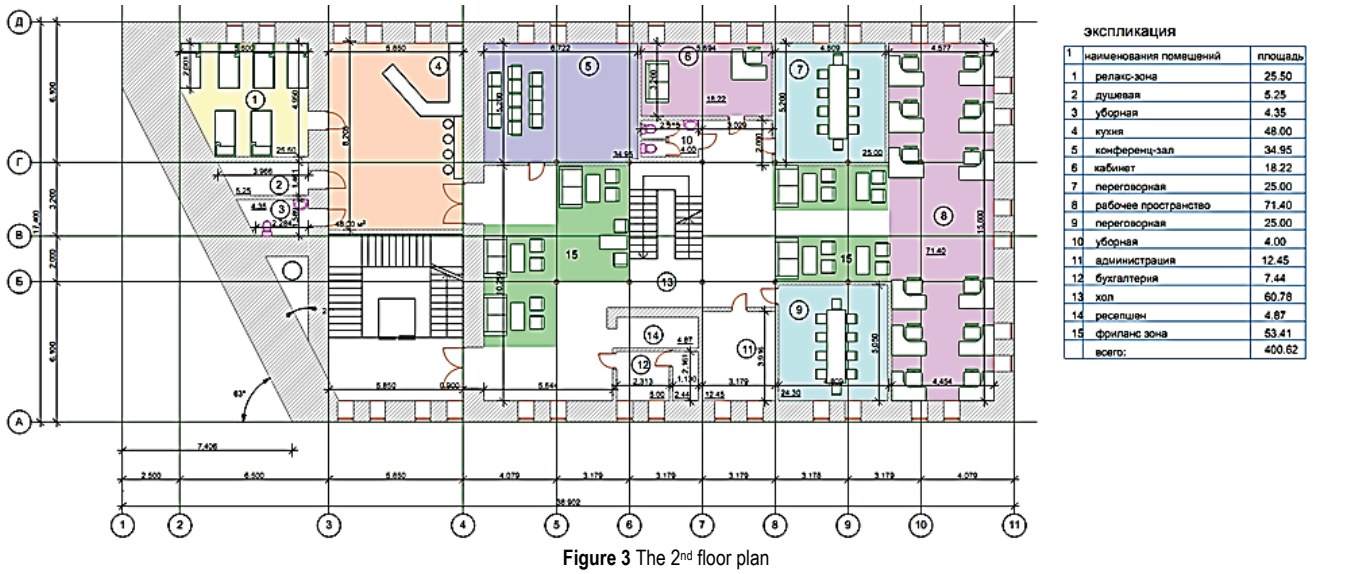

Figure 3 The 2nd floor plan

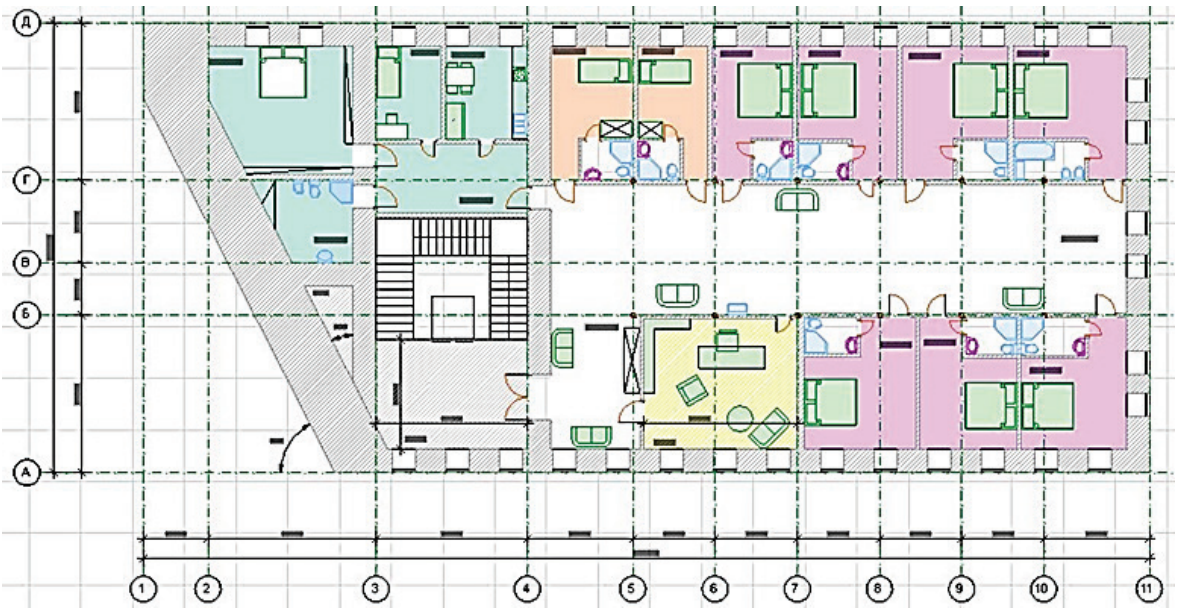

Figure 4 The 4th floor plan

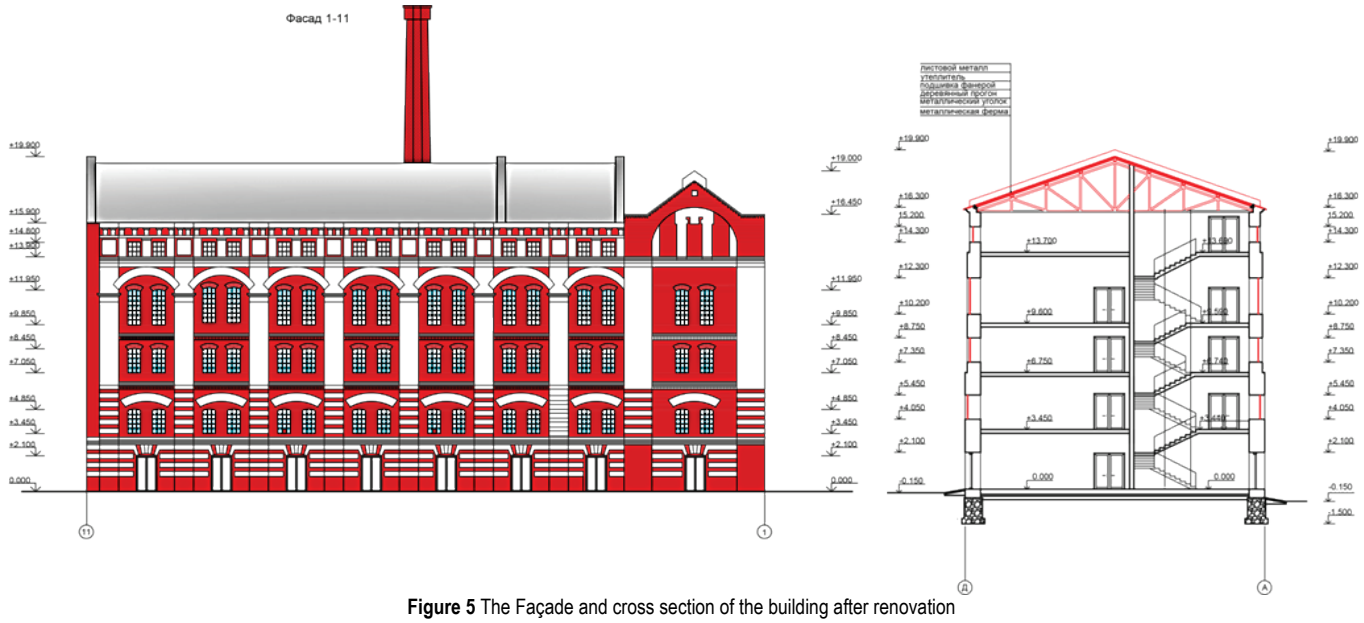

Figure 5 The Façade and cross section of the building after renovation

The old mill building is assumed to be an active cultural and social space with trade and fair zone on the first floor; open working space (coworking) on the second floor; offices on the third floor and hotel rooms on two upper floors. The territory of the embankment is supposed to be cleared and upgraded with some improvements including an access to water (Figs. 3, 4, 5).

Functionality change requires remodeling internal space of the flour mill. The process of reconstruction works has revealed that some areas of exterior walls are in poor conditions and the decision to replace them has been taken. Bricklaying of walls requires installation of temporary multi-layered fixtures that can undertake load from all the preserved frames and beams (Fig. 6).

Temporary fixtures can be dismantled not earlier than in 5 days after the last bricklayer is finished.

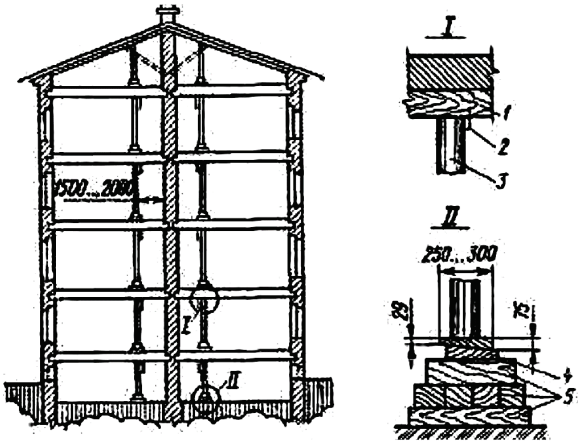

Figure 6 Installation of temporary fixtures: 1 – wooden bar; 2 – bracket; 3 – rack; 4 – wedges; 5 – supporting bars

Before bricklaying procedure, the reasons that have caused the deformation are to be eliminated.

To release the load of the deformed wall, uploading beams are placed from both sides of the wall in the holes above it.

Firstly, the beams are installed in the weakest place of the wall. Pneumatic jackhammers are used to break the holes. Breaking the holes from the other side of the wall is to be started not earlier than in 3 days after the installation of the beam into the first hole. The length of the hole is to be 50 cm longer than the deformed area of the wall. Vertical gaps between beams and bricklaying are filled up with plastic cement mortar, while the gaps between the upper part of the beam and low surface of bricklaying are to be embossed. The fixtures can be dismantled and the new wall loaded on achievement 70% of the project strength [7].

The old flour mill renovation is to be accompanied with recommendations on surrounding area improvements to harmonically adopt the object into the modern urban environment and make it a bright element of the embankment architectural environment attracting tourists and proactive youth. And most importantly, the old mill building which is an industrial architecture landmark will be preserved (Fig. 8).

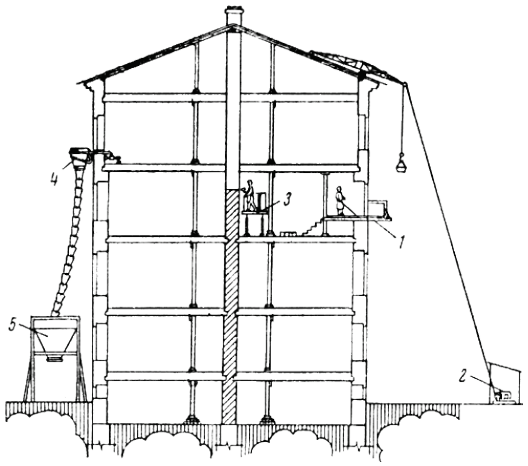

Figure 7 General scheme of works on new bricklaying of the wall with maintenance of existing frames and beams: 1 – a remote reception platform; 2 – an electrical winch; 3 – a scaffolding with inventory bars; 4 – a chain type garbage disposal; 5 – waste disposal bunker [6]

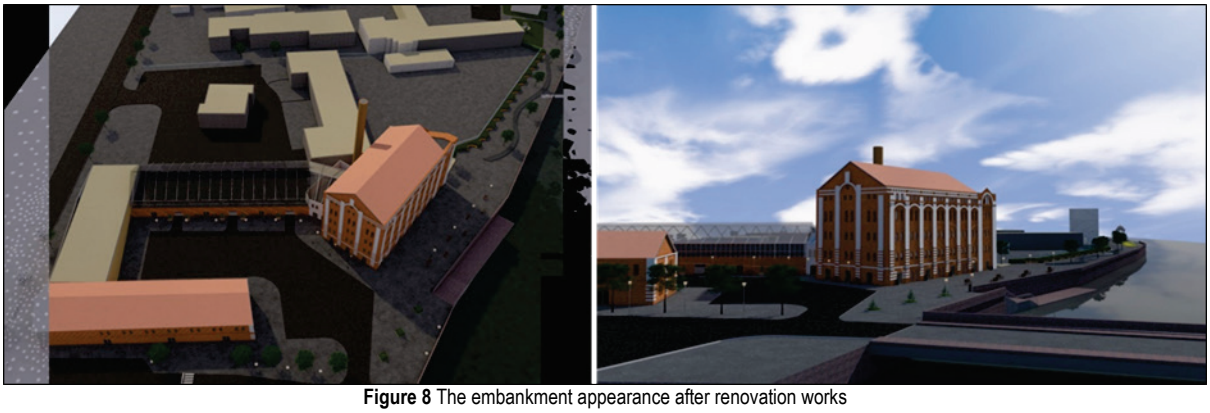

Figure 8 The embankment appearance after renovation works

The suggestions stated above will help attract investments and tourists. As a result, we will have better living conditions in this city block, it will be more visually attractive and you will feel comfortable there.

3 CONCLUSION

The research solves the set goal, which consisted in identifying current trends of adaptation of former industrial territories to new conditions of urban environment, at the same time improving their quality. Based on the analysis of European and American experiences, the emergence of a new type of adaptation of former industrial territories to new conditions of urban environment is improving their quality. Therefore, new social and business centers, techno parks, cultural institutions or loft residential buildings appear on the territories of plants. Experience of industrial zones reconstruction in Ukraine has not been developed enough and today focuses mainly on big cities, in particular Kyiv, Kharkiv, Dnipro.

The master's projects of the students whose specialty is urban construction and environment are presented in the research, on the basis of which new principles and techniques of reconstruction of industrial territories and industrial buildings and structures are revealed. The main goals are defined - formation of unity of unproductive industrial territories by urban territory, increase of visual attractiveness and encouragement to tourist interest, as an object of modern architecture.

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Professional paper

TECHNICAL ASPECT OF CAD AND BIM TECHNOLOGY IN THE ENGINEERING ENVIRONMENT

Matea RISTEVSKI, Mirko KARAKAŠIĆ, Ivan GRGIĆ, Dubravko ŠOTOLA

Abstract: The paper presents advantages and disadvantages of CAD and BIM technology in the engineering environment. Specific attributes of these technologies have been compared to gain the sense of what they represent in the design and planning process. Through the practical design of the project of the cogeneration plant block, it was noted that CAD environment is more acceptable in the detailed design process. On the other hand, BIM environment, compared to CAD, is less flexible in the process of detailed design but provides a more complete data model at the level of the entire product development process.

Keywords: Building Information Modeling (BIM); Computer Aided Design (CAD); Design process

1 INTRODUCTION

Building Information Modeling (BIM) is a technology that aims to build up a rich computer model that forms the basis of the planning process. Using BIM technology leaves the traditional approach to planning, which has the effect of reducing expensive changes to the project, reducing the need for changes and re-use of data needed to manage and maintain the construction [1]. It is a process that follows the construction from the idea until the moment of exploitation and maintenance process. According to [2], it is possible to describe the BIM process as in Fig. 1.

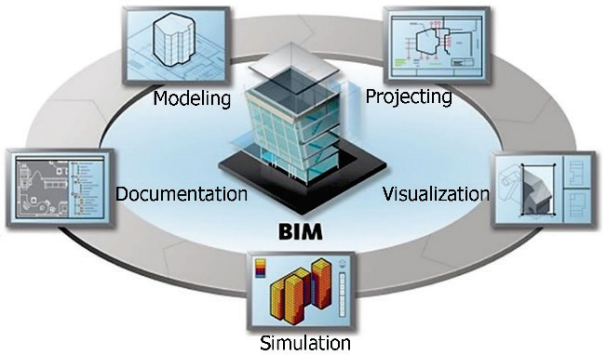


Figure 1 BIM process

With the development of computer technology, CAD systems expand from 2D to 3D computing space. Thus, two-dimensional models replace space models that make up the core of BIM technology. This model complements, in the BIM environment, the following data: geometry, costs, time, sustainability, energy consumption, management and maintenance [1]. The reason why CAD systems complement BIM systems stems from the fact that CAD is highly specialized in the design process (particularly detailed design stage) and with its capabilities does not fully integrate the need for a wide spectrum of data processing resulting from the product development process.

BIM as a technology has its own development process consisting of four levels [2]. The zero level represents the period in which 2D CAD systems were used. Communication between project participants was done with paper and electronic. The first level represents the period in which 2D and 3D CAD systems are combined. There is no clear communication between the project teams. The second level uses 3D CAD systems. Communication between project teams takes place using neutral file formats (IFC formats). The third level represents the integrated work of project teams through a common project model located in a common information environment. This type of work is called "Open BIM".

2 COMPARISON BETWEEN BIM AND CAD TECHNOLOGY

Computer Aided Design (CAD) is a technology that uses computer application in the design process and production of technical documentation. The first CAD systems were oriented only to the two-dimensional drawing, i.e. making technical documentation [3]. During the '60s and early '70s, demands for the expansion 2D CAD systems were introduced with the inclusion of a third dimension [4].

Today's application of feature-based parametric modeling CAD systems that use solid bodies is manifested in the creation of 3D models, technical documentation, geometry definition, analysis using Finite Element Method (FEM) and creation of Computer Numeric Control (CNC) programs. In addition, using 3D solid models is the basis for the development of PDM, ERP and BIM systems. These systems generate intelligent data models (information models) that use 3D models as the basis. This approach gives its users (engineers and architects) opportunities and insights for more effective planning, design, building and project management [1]. Information model, designed by BIM technology, contains the visual 3D model display, geodetic coordinates, material type, material amount, geometric properties, costs, physical properties, etc. This model contains product information from its idea up to recycling.

There are numerous software packages that use BIM technology, such as Autodesk Revit [5]. Since such program packages are extremely expensive, complex and require a certain time to adapt to work in them, their integration into the CAD software package is realized. These solutions make it easier for users to work with BIM because of the already established work in the familiar programming environment.

The application of BIM technology in the modern product development process has many advantages: increasing productivity up to 40%, increasing competitiveness, increasing project quality, using a centralized shared model, and using a single platform which reduces the risk of data transmission errors [1].

3 BLOCK OF THE COGENERATION PLANT

This chapter presents a brief overview of the process of making a 3D model of piping with equipment and armature in accordance with the European norms within the CAD and BIM environment. Model was created according to the process shown in Fig. 2. For the design of the project in CAD environment, the AutoCAD Plant 3D software was used, and Autodesk Revit [5] was used for its design in the BIM environment.

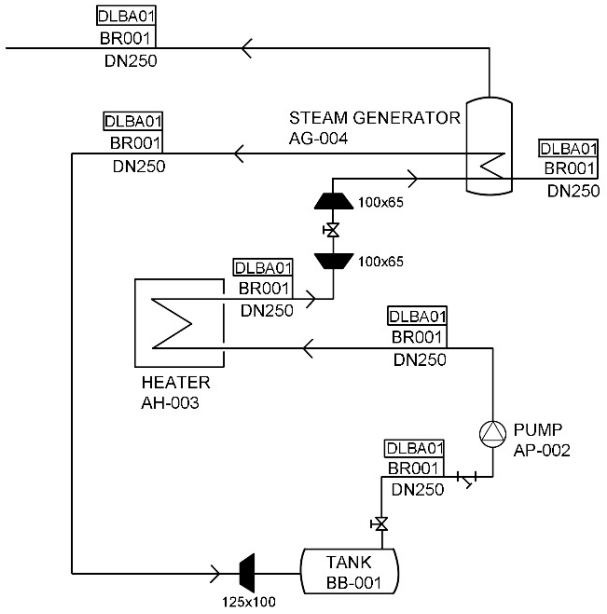


Figure 2 Process according to the P&ID diagram

3.1 Project Design in CAD Environment

According to the P&ID diagram, the project involves defining and installing the following equipment in the AutoCAD Plant 3D model space: block valve – DN100; tank - capacity 600 l, nominal pressure PN16, DN100/DN125; centrifugal pump – capacity 0.3-1 m^3/s, DN65/DN100; booster water heater – DN65 input/output and water vapor generator – DN250 output. Equipment marks correspond to the KKS system [6] and to the specification supported by the AutoCAD Plant 3D.

Modeling process begins with the generation of pipeline armature, using predefined conceptual models in the 3D Piping module. When integrating P&ID diagram into a 3D model, the P&ID Line List is used. By applying such specialized modules within CAD, it is possible to provide a reliable and quick project pipeline design with predefined components and their properties. Block valve DN100 is not a part of Plant 3D; therefore, it is inserted as a block from [7] in a suitable format. Valve is parametrized and it is possible to generate its families, depending on the pressure values and other design parameters (Fig. 3).

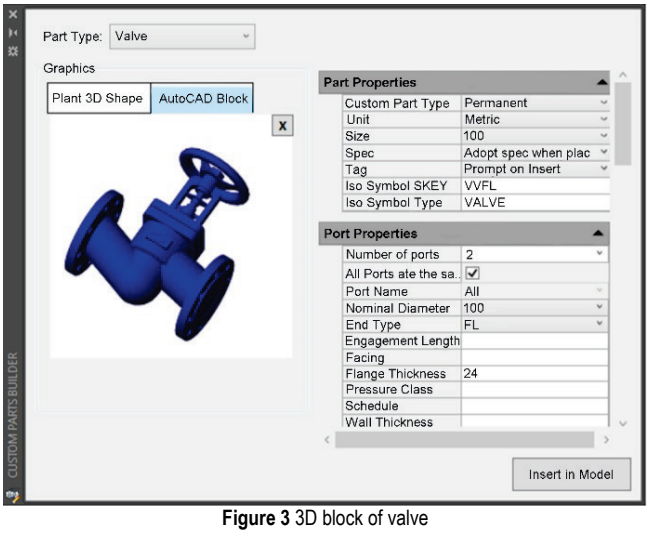


Figure 3 3D block of valve

Tank needs to be dimensioned according to the measurements shown in the Fig. 4. Equipment needs to be placed according to Fig. 5.

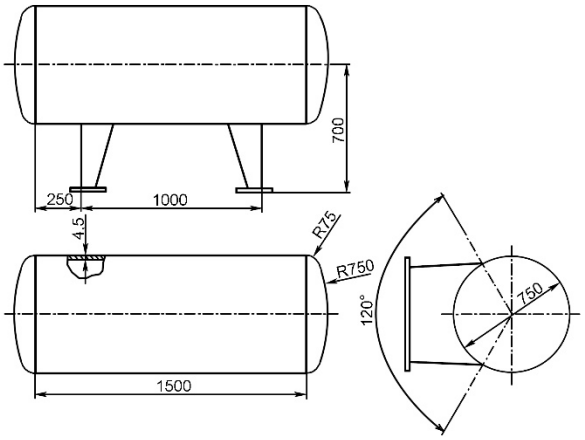


Figure 4 Tank dimensions

Piping identification was performed according to the KKS marking system [6]. In addition, the identification was done according to the Plant 3D specification.

Block valves DN100, KKS marks DLAB01AA001 and DLAB01AA003, are positioned upright (Fig. 6a) and the actuator is directed upward because both piping sections are low enough. In this way, it is possible to operate the actuator smoothly. Arms are also marked with the KKS marks. Fig. 6b shows the arm of steam line whose dimensions are DN250. KKS mark is DLBA01BQ001/2. The final 3D model of the pipeline with equipment and armor made in AutoCAD Plant 3D is shown in Fig. 7.

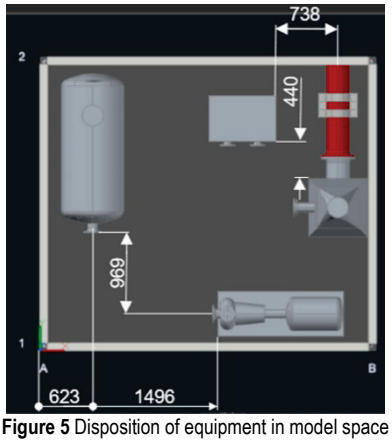
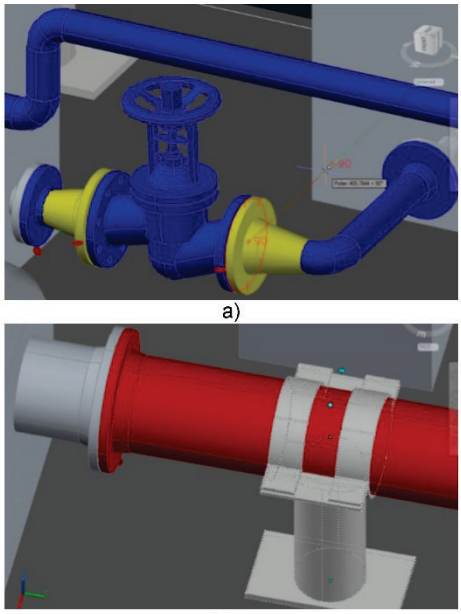


Figure 5 Disposition of equipment in model space



a)

b)

Figure 6 Block valve DN100 and steam line arm DN250

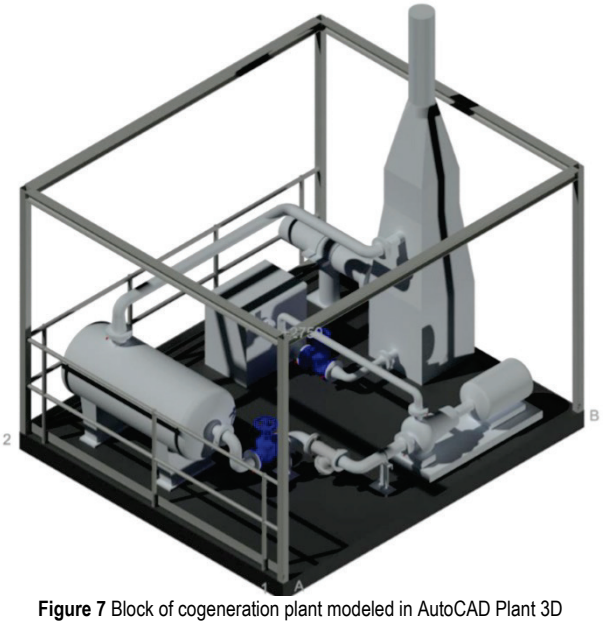


Figure 7 Block of cogeneration plant modeled in AutoCAD Plant 3D

3.2 Project Design in BIM Environment

Pipeline project was developed with Autodesk Revit, i.e. P&ID Modeler module. This module allows creation of 3D pipeline models from 2D P&ID *.dwg* drawings. It is possible to share drawings using the BIM 360 Team service. Main features of the BIM 360 Team are that it combines files and project information, enables data sharing among project team members, review of 3D models and 2D drawings, and allows tracking of workflow on project.

The equipment is placed in workspace with the P&ID Modeler. Also, it is possible to see information that is part of the BIM process description (Fig. 8).

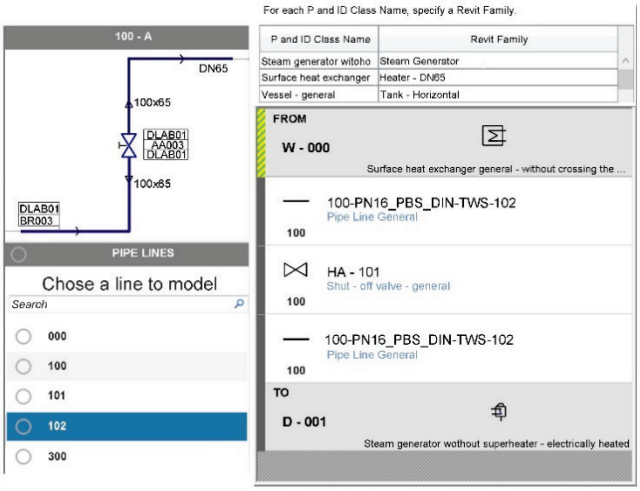


Figure 8 Status information and modification of pipeline model DLAB01BR003

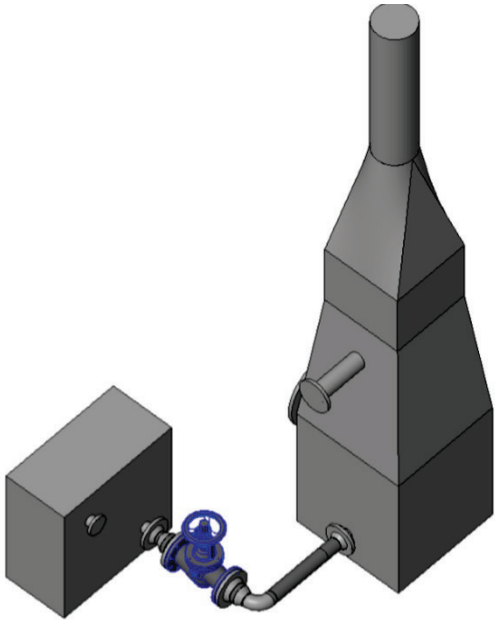


Figure 9 3D model of pipeline DLAB01BR003

Pipeline DLAB01BR003 contains block valve and concentric reducers (Fig. 9). It is necessary to model and place Steam line arms DN250 (Fig. 6b) in the piping model. This is Revit's shortcoming, because there is no fully defined

component base. In this way, the duration of the design process is extended.

During Revit production of technical documentation, the pipeline isometric overview is a problem. Revit is extremely weak, and some of its disadvantages are impossibility of connection elements with 3D model, complex dimensioning, a modest symbol base, symbols are appropriated for 2D description, and the workspace is open. Fig. 10 shows the drawing of pipeline part in isometry.

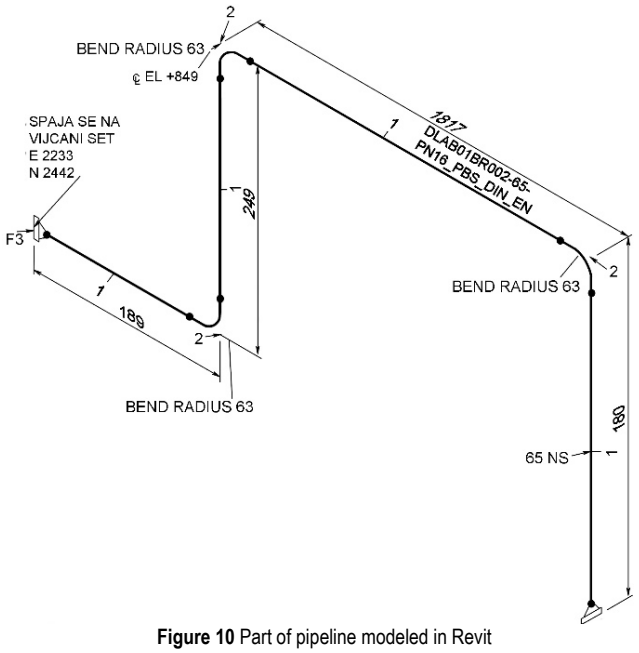


Figure 10 Part of pipeline modeled in Revit

4 CONCLUSION

BIM technology is rich with the information and follows the product development process from the beginning (concept) to the end (recycling). In the case of specific projects, such as the process industry pipelines, CAD is significantly ahead. Reasons lie in advanced modules that are more adjusted to a particular area. During the production of technical documentation and isometric representation of the pipeline model, Revit showed some limitations regarding Plant 3D.

CAD tools (such as AutoCAD Plant 3D) are more complete for pipeline engineering. The disadvantage is obvious in the view of a complete data model, which lacks information that is not related to the design process.

Taking into account the time required for project development, due to good and high quality preparation, AutoCAD Plant 3D proved to be a more flexible platform than Revit. The reason lies in the fact that at the beginning of the project the equipment is directly made in Plant 3D and in this way enables it to adapt to the further needs of the project. In Revit, however, such a step requires adaptation of existing families, i.e. the creation of new components of the plant.

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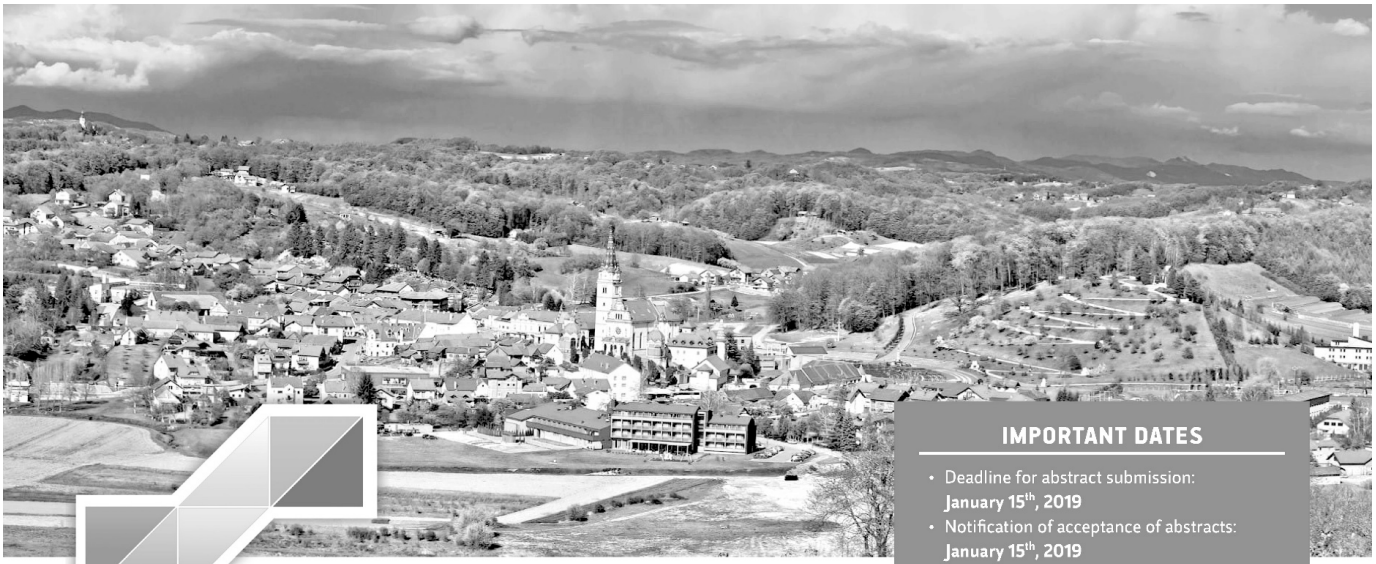

MOTSP2019

Management of Technology – Step to Sustainable Production
11th International Scientific Conference

Industry 5.0 – Return to Humanity

June 5 – 7 2019, Marija Bistrica, Croatia

FIRST CALL FOR PAPERS

International Conference Management of Technology – Step to Sustainable Production, will take place from 5th to 7th June 2019 in Marija Bistrica (36 km from Zagreb), Croatia, as a joint project organized by the Faculty of Mechanical Engineering and Naval Architecture, Croatian Association for PLM, Warsaw University of Technology – Faculty of Transport and the University of North, Koprivnica.

The main objective of this Conference is to bring together international experts from academic entities, research laboratories and industries related to the field of Management of Technology and Sustainable Production. The Conference will also provide a platform for sharing of the knowledge, ideas and results between science and industry.

The management of technology, stimulation of innovation and invention and transfer of technology are important challenges both the developed countries and countries in transition.

CONFERENCE VENUE

Bluesun, hotel Kaj (www.hotelkaj.hr/en/)
Zagrebačka bb, 49246 Marija Bistrica

Participants and accompanying persons of MOTSP 2019 have a special offer from the Hotel Kaj (****), Marija Bistrica.

CONFERENCE FEES

Early registration fee until April 15, 2019: **€430**
Late registration fee: **€460**
Deadline for registration fee payment:
May 15, 2019

The Conference fee includes welcome drink, attendance to all sessions, proceedings, two lunches, coffee breaks, social events, etc.

JOURNALS

All the accepted papers will be published in the Conference Proceedings to be distributed during the Conference.

Reviewers and Scientific Committee will recommend three papers that will be nominated as the best papers and would be prizewinning in three categories.

According to the Scientific Committee recommendations, the authors of the selected papers will also be invited to submit the extended versions of their papers for publication in the following journals (some of them are indexed in CC, SCI and SCI – Expanded databases):

- Transaction of FAMENA (SCI Expanded)
- Technical Gazette (SCI Expanded)
- Technical Journal (WOS)
- International Journal of Product Lifecycle Management

IMPORTANT DATES

- Deadline for abstract submission: **January 15th, 2019**
- Notification of acceptance of abstracts: **January 15th, 2019**
- Final submission of full papers: **March 1st, 2019**
- Notification of acceptance of full papers: **Until April 30th, 2019**

CONFERENCE LANGUAGE

- English

FSB 100 CaPLM Croatian Association for PLM

University North

Warsaw University of Technology, Faculty of Transport, Poland

MAIN TOPICS

- Management of Technology
- Production, Operation Management
- Strategic Management
- Engineering Management
- Industrial Engineering
- Sustainable Production and Development
- Social Responsibility
- Artificial Intelligence
- Financial Sustainability
- Sustainable Transport Management
- Transport Technology and Organization
- other fields

CONTACTS

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  gbaric@fsb.hr
- url: **www.motsp.eu**
- e-mail: **motsp@fsb.hr**

ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20.....

14pt
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ARTICLE TITLE ONLY IN ENGLISH (Style: Arial Narrow, Bold, 14pt)

14pt

Ivan HORVAT, Thomas JOHNSON (Style: Arial Narrow, Bold, 11pt)

14pt

Abstract: Article abstract contains maximum of 150 words and is written in the language of the article. The abstract should reflect the content of the article as precisely as possible. TECHNICAL JOURNAL is a trade journal that publishes scientific and professional papers from the domain(s) of mechanical engineering, electrical engineering, civil engineering, multimedia, logistics, etc., and their boundary areas. This document must be used as the template for writing articles so that all the articles have the same layout. (Style: Arial Narraw, 8pt)

8pt

Keywords: keywords in alphabetical order (5-6 key words). Keywords are generally taken from the article title and/or from the abstract. (Style: Arial Narraw, 8pt)

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1 ARTICLE DESIGN
(Style: Arial Narrow, Bold, 10pt)

10pt

(Tab 6 mm) The article is written in Latin script and Greek symbols can be used for labelling. The length of the article is limited to eight pages of international paper size of Letter (in accordance with the template with all the tables and figures included). When formatting the text the syllabification option is not to be used.

10pt

1.1 General guidelines
(Style: Arial Narrow, 10pt, Bold, Align Left)

10pt

The document format is Letter with margins in accordance with the template. A two column layout is used with the column spacing of 10 mm. The running text is written in Times New Roman with single line spacing, font size 10 pt, alignment justified.

Article title must clearly reflect the issues covered by the article (it should not contain more than 15 words).

Body of the text is divided into chapters and the chapters are divided into subchapters, if needed. Chapters are numbered with Arabic numerals (followed by a period). Subchapters, as a part of a chapter, are marked with two Arabic numerals i.e. 1.1, 1.2, 1.3, etc. Subchapters can be divided into even smaller units that are marked with three Arabic numerals i.e. 1.1.1, 1.1.2, etc. Further divisions are not to be made.

Titles of chapters are written in capital letters (uppercase) and are aligned in the centre. The titles of subchapters (and smaller units) are written in small letters (lowercase) and are aligned left. If the text in the title of the subchapter is longer than one line, no hanging indents.

10pt

Typographical symbols (bullets), which are being used for marking an item in a list or for enumeration, are placed at a beginning of a line. There is a spacing of 10pt following the last item:

- Item 1
- Item 2
- Item 3

10pt

The same rule is valid when items are numbered in a list:

1. Item 1
2. Item 2
3. Item 3

10pt

1.2 Formatting of pictures, tables and equations
(Style: Arial Narrow, 10pt, Bold, Align Left)

10pt

Figures (drawings, diagrams, photographs) that are part of the content are embedded into the article and aligned in the centre. In order for the figure to always be in the same position in relation to the text, the following settings should be defined when importing it: text wrapping / in line with text.

Pictures must be formatted for graphic reproduction with minimal resolution of 300 dpi. Pictures downloaded from the internet in ratio 1:1 are not suitable for print reproduction because of unsatisfying quality.

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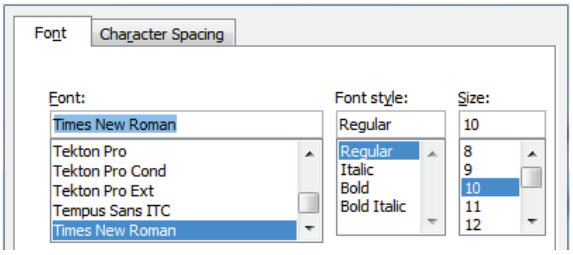

Figure 1 Text under the figure [1]
(Style: Arial Narraw, 8pt, Align Centre)

10pt

The journal is printed in black ink and the figures have to be prepared accordingly so that bright tones are printed in a satisfactory manner and are readable. Figures are to be in colour for the purpose of digital format publishing. Figures in the article are numbered with Arabic numerals (followed by a period).

Text and other data in tables are formatted - Times New Roman, 8pt, Normal, Align Center.

When describing figures and tables, physical units and their factors are written in italics with Latin or Greek letters,

while the measuring values and numbers are written upright.
10pt

Table 1 Table title aligned centre
(Style: Arial Narraw, 8pt, Align Centre)

	1	2	3	4	5	6
ABC	ab	ab	ab	ab	ab	ab
DEF	cd	cd	cd	cd	cd	cd
GHI	ef	ef	ef	ef	ef	ef

10 pt

Equations in the text are numbered with Arabic numerals inside the round brackets on the right side of the text. Inside the text they are referred to with equation number inside the round brackets i.e. ".... from Eq. (5) follows ...." (Create equations with MathType Equation Editor - some examples are given below).
10pt

$$F_{\text{avg}}(t,t_0)=\frac{1}{t}\int_{t_0}^{t_0+t}F\big(q(\tau),p(\tau)\big)\,\mathrm{d}\tau, \tag{1}$$

10pt

$$\cos\alpha+\cos\beta=2\cos\frac{\alpha+\beta}{2}\cdot\cos\frac{\alpha-\beta}{2}. \tag{2}$$

10pt

Variables that are used in equations and also in the text or tables of the article are formatted as *italics* in the same font size as the text.

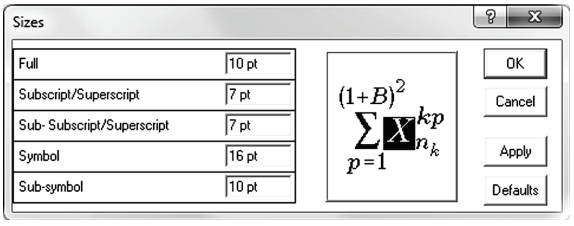

Figure 2 The texts under figures
(Style: Arial Narraw, 8pt, Align Centre)

Figures and tables that are a part of the article have to be mentioned inside the text and thus connected to the content i.e. „ … as shown in Fig. 1…" or „data from Tab. 1…" and similar.
10pt

2 PRELIMINARY ANNOTATION

10pt

Article that is offered for publication cannot be published beforehand, be it in the same or similar form, and it cannot be offered at the same time to a different journal. Author or authors are solely responsible for the content of the article and the authenticity of information and statements written in the article.

Articles that are accepted for publishing are classified into four categories: original scientific papers, preliminary communications, subject reviews and professional papers.

Original scientific papers are articles that according to the reviewer and the editorial board contain original theoretical or practical results of research. These articles need to be written in such a way that based on the information given, the experiment can be repeated and the results described can be achieved together with the author's observations, theoretical statements or measurements.

Preliminary communication contains one or more pieces of new scientific information, but without details that allow recollection as in original scientific papers. Preliminary communication can give results of an experimental research, results of a shorter research or research in progress that is deemed useful for publishing.

Subject review contains a complete depiction of conditions and tendencies of a specific domain of theory, technology or application. Articles in this category have an overview character with a critical review and evaluation. Cited literature must be complete enough to allow a good insight and comprehension of the depicted domain.

Professional paper can contain a description of an original solution to a device, assembly or instrument, depiction of important practical solutions, and similar. The article need not be related to the original research, but it should contains a contribution to an application of known scientific results and their adaptation to practical needs, so it presents a contribution to spreading knowledge, etc.

Outside the mentioned categorization, the Editorial board of the journal will publish articles of interesting content in a special column. These articles provide descriptions of practical implementation and solutions from the area of production, experiences from device application, and similar.
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3 WRITING AN ARTICLE

10pt

Article is written in the English language and the terminology and the measurement system should be adjusted to legal regulations, standards (ISO 80 000 series) and the SI international system of units. The article should be written in third person.

Introduction contains the depiction of the problem and an account of important results that come from the articles that are listed in the cited literature.

Main section of the article can be divided into several parts or chapters. Mathematical statements that obstruct the reading of the article should be avoided. Mathematical statements that cannot be avoided can be written as one or more addendums, when needed. It is recommended to use an example when an experiment procedure, the use of the work in a concrete situation or an algorithm of the suggested method must be illustrated. In general, an analysis should be experimentally confirmed.

Conclusion is a part of the article where the results are being given and efficiency of the procedure used is emphasized. Possible procedure and domain constraints where the obtained results can be applied should be emphasized.
10pt

4 RECAPITULATION ANNOTATION

10pt

In order for the articles to be formatted in the same manner as in this template, this document is recommended for use when writing the article. Finished articles written in MS Word for Windows and formatted according to this

template must be submitted using our The Paper Submission Tool (PST) (https://tehnickiglasnik.unin.hr/authors.php) or eventually sent to the Editorial board of the Technical Journal to the following e-mail address: tehnickiglasnik@unin.hr

The editorial board reserves the right to minor redaction corrections of the article within the framework of prepress procedures. Articles that in any way do not follow these authors' instructions will be returned to the author by the editorial board. Should any questions arise, the editorial board contacts only the first author and accepts only the reflections given by the first author.

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5 REFERENCES (According to APA)

10pt

The literature is cited in the order it is used in the article. Individual references from the listed literature inside the text are addressed with the corresponding number inside square brackets i.e. "… in [7] is shown …". If the literature references are web links, the hyperlink is to be removed as shown with the reference number 8. Also, the hyperlinks from the e-mail addresses of the authors are to be removed. In the literature list, each unit is marked with a number and listed according to the following examples (omit the subtitles over the references – they are here only to show possible types of references):

9pt

[1] See http://www.bibme.org/citation-guide/apa/

[2] See http://sites.umuc.edu/library/libhow/apa_examples.cfm

[3] (Style: Times New Roman, 9pt, according to APA)

[4] Amidzic, O., Riehle, H. J., & Elbert, T. (2006). Toward a psychophysiology of expertise: Focal magnetic gamma bursts as a signature of memory chunks and the aptitude of chess players. *Journal of Psychophysiology, 20*(4), 253-258. https://doi.org/10.1027/0269-8803.20.4.253

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[6] Jans, N. (1993). *The last light breaking: Life among Alaska's Inupiat Eskimos*. Anchorage, AK: Alaska Northwest Books.

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[8] Chaffe-Stengel, P., & Stengel, D. (2012). *Working with sample data: Exploration and inference*. https://doi.org/10.4128/9781606492147

[9] Freitas, N. (2015, January 6). People around the world are voluntarily submitting to China's Great Firewall. Why? Retrieved from http://www.slate.com/blogs/future_tense/2015/01/06/tencent_s_wechat_worldwide_internet_users_are_voluntarily_submitting_to.html
(Style: Times New Roman, 9pt, according to APA)

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Authors' contacts:

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Tel./Fax, e-mail

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