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EMPIRICAL MODELS' APPLICABILITY FOR CALCULATING THE CENTRIFUGAL PUMP'S IMPELLERS GEOMETRIC PARAMETERS

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Abstract. This paper deals with the comparison of empirical computational models used to achieve the geometrical parameters of pumps impellers with models based on Computational Fluid Dynamics (CFD) simulations and optimization algorithms. Also, the actuality of the empirical models application in modern pump manufacturing industry is analyzed. Further, an empirical model for calculating the pump impeller geometrical parameters was presented. Applying this model, the calculation of the centrifugal pump impeller parameters for CH 6,3/20 1,1-2 canned motor pump was performed. The procedure for parameterization and generation of the geometric model based on parameters obtained from this model through ANSYS DesignModeler was also presented. CFD simulation based on ANSYS CFX was used to obtain the operating characteristic of the obtained centrifugal pump impeller. The authors carried out the comparison of the results of the designed model with the original one and with the optimized impeller obtained using optimization algorithms and CFD calculations.

Keywords: *pump impeller, centrifugal pumps, analytical calculation, CFD simulations.*

Rezumat. În această lucrare este prezentată compararea modelelor de calcul empirice utilizate pentru realizarea parametrilor geometrici ai rotoarelor pompelor cu modele bazate pe simulări CFD și algoritmi de optimizare. De asemenea, este analizată actualitatea aplicării modelelor empirice în industria modernă de fabricare a pompelor. Totodată, a fost prezentat un model empiric pentru calcularea parametrilor geometrici ai rotorului pompei. Aplicând acest model, s-a efectuat calculul parametrilor rotorului pompei centrifuge pentru pompă centrifugă cu motor capsulat CH 6,3/20 1,1-2. A fost prezentată procedura de parametrizare și generare a modelului geometric pe baza parametrilor obținuți din acest model prin intermediul ANSYS DesignModeler. Simularea CFD bazată pe ANSYS CFX a fost utilizată pentru a obține caracteristicele de funcționare a rotorului pompei centrifuge. Rezultatele modelului proiectat au fost comparate cu cel original și cu rotorul optimizat obținut folosind algoritmi de optimizare și calcule CFD.

Cuvinte cheie: *rotorul pompei, pompe centrifuge, calcul analitic, simulări CFD.*

1. Introduction

Obtaining the geometry of turbomachines impellers is a complex problem, which can be solved in several ways: the application of empirical models [1], based on experimentally obtained data; specialized software that automates previous models [2,3]; and optimizations based on Computational Fluid Dynamics (CFD) simulations and optimization algorithms [4–7].

The paper presents the application of an empirical model to obtain a rotor with enhanced characteristics.

Since the beginning of the 20th century, due to more determination of the parameters of fluid flow in the working parts of centrifugal pumps, empirical models for calculating the working parts of centrifugal pumps have obtained their contemporary form. To obtain the geometry of the pump parts, design engineers made use of the empirical mathematical models presented in the works of Pfleiderer (Germany, 1924), Stepanoff (USA, 1948), Lomakin (USSR, 1950) etc.

Before the massive application of CFD simulations, the design of pump working parts was reduced to a large number of experimental iterations [8], with the geometry of the pump parts changing at each optimization stage. In this paper, the optimized impeller received by applying CFD simulations together with optimization algorithms [9], was compared with the impeller obtained using analytical methods (primarily based on the model evolution presented in the work [10]).

2. Theoretical considerations about centrifugal pump efficiency

The authors selected the centrifugal pump efficiency as the investigated criterion. The Pump efficiency η represents the ratio of useful power P_u and delivered power P and can be represented by the following relation [11]:

$$\eta = \frac{P_u}{P} = \frac{\rho g Q H}{P}, \tag{1}$$

where: P is the total power,

P_u – used power,

Q – fluid flow rate measured at the discharge pump connection,

H – pump head.

The losses in the centrifugal pump, in case of a centrifugal pump with a canned motor (Figure 1) in its pumping part, are divided into hydraulic, volumetric, and mechanical losses. The efficiency of the pumping part is calculated by Eq. (2) [8, 12–15]:

$$\eta_{p.m.} = \eta_m \eta_h \eta_v, \tag{2}$$

where*:* η_h is the hydraulic efficiency, η_v is the volumetric efficiency, and η_m is the mechanical efficiency.

Hydraulic efficiency η_h of a centrifugal pump indicates the efficiency a pump converts the mechanical energy supplied by the electric motor into the hydraulic energy of the pumped fluid [8, 10–12,16–19]:

$$\eta_h = \frac{H_t - \Sigma h}{H_t}, \tag{3}$$

where: H_t is the theoretical pump head, and Σh is the sum of the hydraulic losses.

The following logarithmic relation is given for the preventive determination of the hydraulic efficiency η_h [5]:

$$\eta_h = 0{,}7 + 0{,}0835 lg D_q, \quad (4)$$

where: parameter $D_q = 4\sqrt[3]{\frac{Q}{n}}$ is the nominal diameter, *n* being the pump shaft speed.

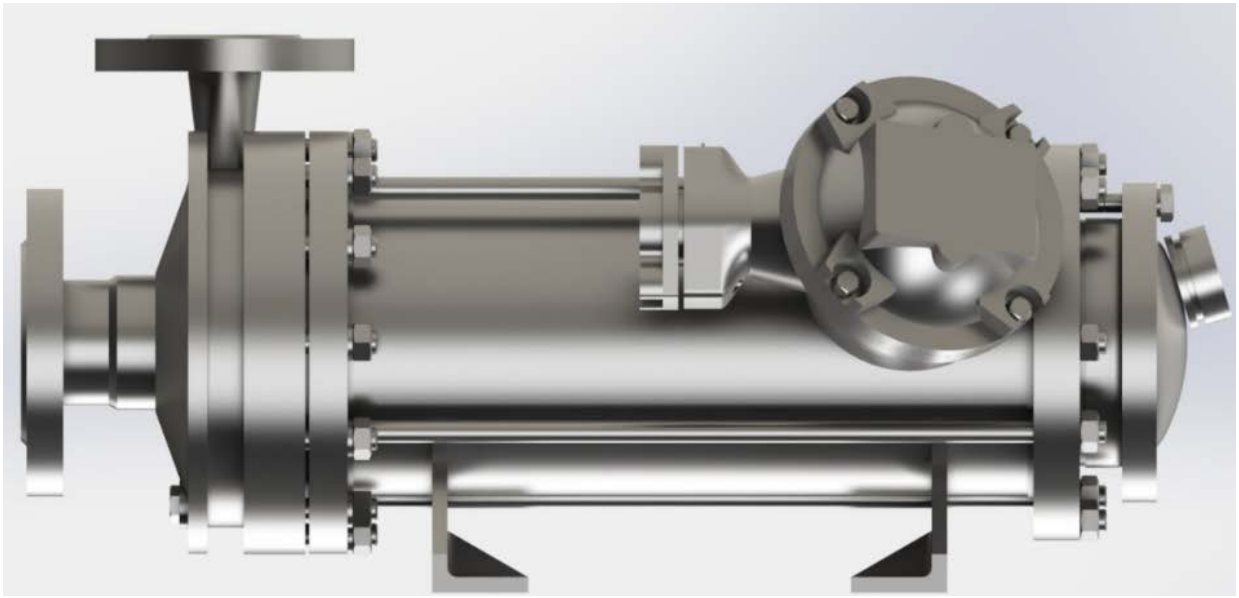


Figure 1. Representation of the pump model CH 6,3/20 1,1-2.

Hydraulic losses. The first type of energy loss in a pump is the one caused by the hydraulic resistance to flow movement in the working parts of the pump being exceeded [17]. By the friction losses during fluid movement in the channels of the flowing part of the pump and losses due to the formation of vortices associated with the separation of the fluid when flowing around different elements of the working parts of the pump [11].

Hydraulic losses occur due to frictional forces within the fluid, formation of areas of increased turbulence, variation of flow direction, variation of the area and cross-sectional shape of the pump part channels and losses caused due to flow separation from the impeller walls.

The volumetric efficiency η_v of a centrifugal pump points out the efficiency of conveying the fluid flow. It is equal to the ratio of the pump's actual flow rate *Q* to the ideal flow rate Q_i [8,10–12, 16–19]:

$$\eta_v = \frac{Q}{Q_i} = \frac{Q}{Q+Q_P}, \quad (5)$$

where*:* Q_i is the total flow and Q_p is the lost flow.

For achieving the preventive determination of volumetric efficiency η_v the following relation was used [10,11,18]:

$$\eta_v = \frac{1}{1+0{,}68 \cdot n_s^{-\frac{2}{3}}}. \quad (6)$$

Volume losses occur in the gaps between rotating and stationary parts, where fluid leaks occur, reducing pump flow. Volume losses in the pump are often related to the liquid flow from the impeller's discharge area to its suction area. In order to minimize the leakage flow due to pressure differences, the fit between the impeller and the pump casing is reduced to a maximum [11,18].

Mechanical efficiency η_m of the centrifugal pump is the ratio of the power delivered by the motor to the useful mechanical power of the pump [8,10–12,16–19]:

$$\eta_m = \frac{P_M - \Delta P}{P_M} = 1 - \frac{\Delta P}{P_M}. \quad (7)$$

The following relation is used in the preventive determination of the mechanical efficiency η_m [11]:

$$\eta_m = \frac{1}{1+\frac{820}{n_S{}^2}}. \quad (8)$$

Mechanical losses are due to friction of the bearings, shaft seals and friction of the outer surface of the impellers with the liquid (friction of the hub and shroud disks) [16,17]. Mechanical losses are divided into internal and external losses [11].

The external mechanical losses depend on the shaft dimensions, the type of end seals and the rotational speed of the impeller and are attested in seals, slide bearings and journals. Internal mechanical losses represent the losses occurred through hydraulic friction of the hub and shroud disks.

For centrifugal canned motor CH and CMP type pumps, where the pumping part and the electric motor are joined by a shaft, the total efficiency of the pump represents the result of multiplying of the efficiencies of the pumping part and the electric motor:

$$\eta = \eta_{p.m.} \cdot \eta_{m.e.} = \eta_m \eta_h \eta_v \cdot \eta_{m.m.} \eta_{e.m.}, \quad (9)$$

where: $\eta_{m.m.}$ is the mechanical efficiency of the electric motor,

$\eta_{e.m.}$ is the electromagnetic efficiency of the pump's electric motor.

We can mention that during the study the pump's electric motor has not been modified, its efficiency remained constant ($\eta_{m.m.} = \eta_{e.m.} = const$). As the mechanical and volumetric efficiency of the pump impeller did not change considerably, it can also be considered constant ($\eta_m = \eta_v = const$), therefore in the given case, the study of the variation on the pump impeller hydraulic efficiency is of interest η_h.

3. Modelling the geometry of the centrifugal pump impeller

The empirical model described in [10,11,16–19], was used to obtain the parameters of the geometrical model of the pump impeller. We can mention the main relations of calculation of the centrifugal pump impeller parameters:

First, we determine the type of pump according to the corresponding specific speed [11,18]:

$$n_s = \frac{3{,}65 \cdot n\sqrt{Q}}{H^{\frac{3}{4}}}, \quad (10)$$

where: *n* is the impeller rotational frequency, *Q* is the pump flow rate at the pump outlet, and *H* is the pumping head.

To determine the dimensions of the impeller hub, we need to determine the shaft dimensions, taking into account the pump power [10,11,18]:

$$P = \frac{\rho g Q H}{\eta}.$$

The shaft diameter is calculated [10,11,18] with the following relation:

$$d = 170\sqrt[3]{\frac{P}{\pi \tau_{cr}}}., \quad (11)$$

where: P is pump power and τ_{cr} - permissible mechanical stress at twisting.

Diameter of the impeller bushing is determined by relation [10,11,18]:

$$d_n = d(1{,}25 \div 1{,}5). \tag{12}$$

The inlet speed of the centrifugal pump is determined by the following relation:

$$v_0 \approx 0{,}06\sqrt[3]{Qn^2}.$$

The impeller's inlet diameter D_0 is calculated from the relation presented below, resulting from the fluid flow continuity equation [11]:

$$D_0 = \sqrt{\frac{4Q}{\pi\eta_v v_0} + d^2}, \tag{13}$$

where: $v_0 \approx 0{,}06\sqrt[3]{Qn^2}$ is the speed value at the inlet to the centrifugal pump.

The diameter of the blade's leading edge is established as follows:

$$D_1 = D_0 + (2 + 10)mm. \tag{14}$$

The transport speed at the impeller's blade inlet is set:

$$u_1 = \frac{\pi D_1 n}{60}. \tag{15}$$

The absolute velocity at the leading edge of the blade is calculated as below:

$$v_1 = \frac{v_0}{\psi_1}, \tag{16}$$

where: ψ_1 is the coefficient of contraction of the liquid stream by the blade.

The width of the blade at the impeller inlet is taken:

$$b_1 = 1 - \frac{Q}{\pi D_1 v_1}. \tag{17}$$

The angle of the blade is set as follows:

$$\beta_1 = arctg\frac{v_{1r}}{u_1}. \tag{18}$$

The angle obtained is increased by angle of attack $\Delta\beta_1 = 3 \div 8°$.

Constructive angle β_{1l} is determined by the following relation:

$$\beta_{1l} = \beta_1 + \Delta\beta_1,$$

where: $\Delta\beta_1 = 3 \div 8°$ is the angle of attack.

The impeller diameter is determined by the following relation:

$$D_2 = \frac{60u_2}{\pi n}, \tag{19}$$

where $u_2 = K_{u_2}\sqrt{2gH_t}$, velocity u_2 at impeller outlet.

According to Pfleiderer's relation the number of blades Z is determined as follows:

$$Z = 6{,}5\frac{D_2 + D_1}{D_2 - D_1} sin\left(\frac{\beta`_2 - \beta`_1}{2}\right), \tag{20}$$

where: in the first approximation [10,18]: $\beta`_1 = \beta_1 = 15 \div 30°$ and $\beta`_2 = \beta_2 = 18 \div 20°$.

The number of blades received is rounded up to a whole number.

The analytical calculation of the geometrical parameters of the pump CH 6,3/20 1,1-2 impeller (Figure 2) was performed in the MathCad environment. The results are shown in Table 1.

Table 1

Blade construction parameters

Inlet diameter D_0, mm	Impeller channel width at inlet b_1, mm	Impeller channel width at outlet b_2, mm	Impeller diameter D_2, mm	Number of blades Z	Specific speed n_s	Impeller efficiency (indicative)
26	31.75	12.75	128	6	47.62	0.8

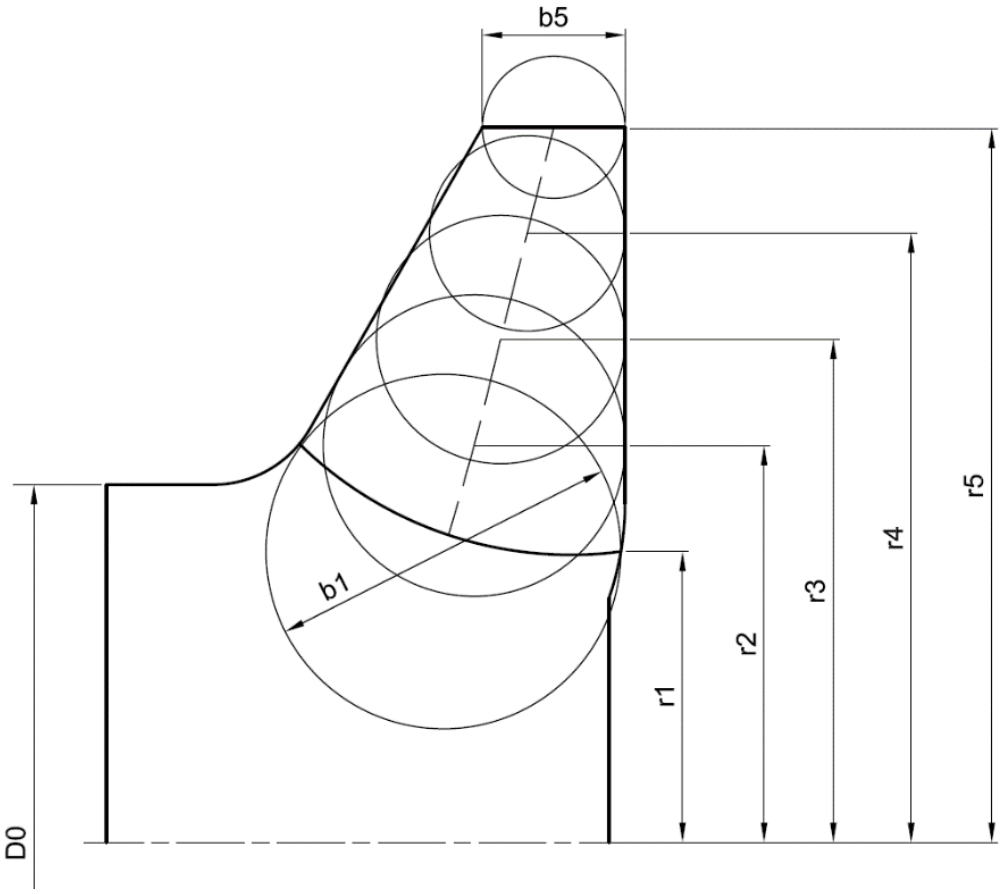


Figure 2. Modelling of the meridian section of pump impeller.

The differential equation of the blade profile in the plane is [10,11,18]:

$$r \cdot d\theta = \frac{dr}{tg\beta}. \tag{21}$$

From relation (21), we obtain the angle of deployment of the blade [10,11,18]:

$$\theta = \frac{180}{\pi}\int_{r_1}^{r_2}\frac{dr}{rtg\beta}. \tag{22}$$

The blade angle at any point surveyed at radius *r* can be determined if the distribution of relative velocity *w* and meridional velocity is known $a`_m$ without considering the compression along the radius and the thickness of the blade *S* along the length of the radius:

$$sin\beta = \frac{S}{t} + \frac{a`_m}{\omega}. \tag{23}$$

When integrating the relation (22) we obtain:

$$B(r) = \frac{1}{rtg\beta}. \tag{24}$$

At the end of the blade profiling, calculate, for any radius r_K, the wrap angle [10,11,18]:

$$\theta_K = \frac{180}{\pi}\sum_{i=1}^{K}\frac{B_1+B_{i+1}}{2}\Delta r_i. \quad (25)$$

The determination of the palette parameters was also carried out according to the methodology performed in [10] and is shown in Table 2.

Table 2

Blade construction parameters

Pos.	Radial coordinate r_k, mm	Impeller channel width b, mm	Axial velocity v'_m, m/s	Relative speed w, m/s	Pitch t, mm	Blade thickness δ, mm	Plate angle β°	Deployment angle θ°
1	26	31.75	2.58	11.95	27.21	2.50	17.92	0
2	35.5	27	2.99	11.68	37.16	3.00	19.70	27.51
3	45	22.25	3.13	11.41	47.10	3.50	20.40	48.37
4	54.5	17.5	2.98	11.14	57.04	3.25	18.94	65.15
5	64	12.75	2.55	10.86	66.99	3.00	16.23	79.15

4. Determination of impeller parameters obtained in ANSYS Workbench

4.1. Forming the geometric model in ANSYS DesignModeler

The geometric module used in the study was obtained in ANSYS DesignModeler. The ANSYS BladeEditor tool was applied to obtain the parameterized geometric model, Figure 3.

The blade geometry was parameterized by varying the angle β of the blade at 5 points, keeping the blade thickness distribution constant along the length of the blade. The values of angle β were recalculated considering the direction of the pump's impeller rotation and entered as input parameters in the DesignModeler environment, Figure 4.

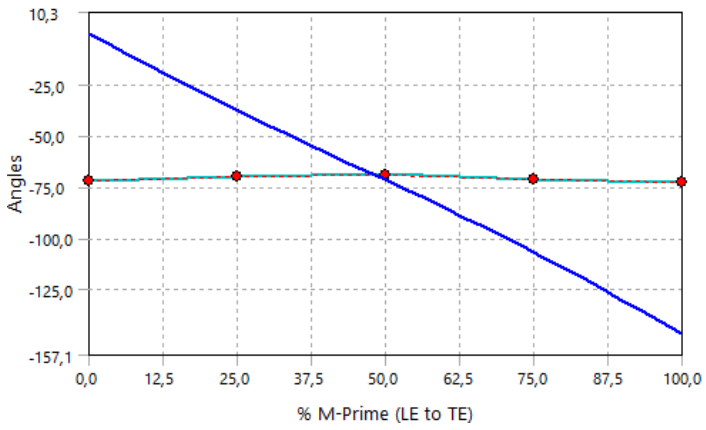
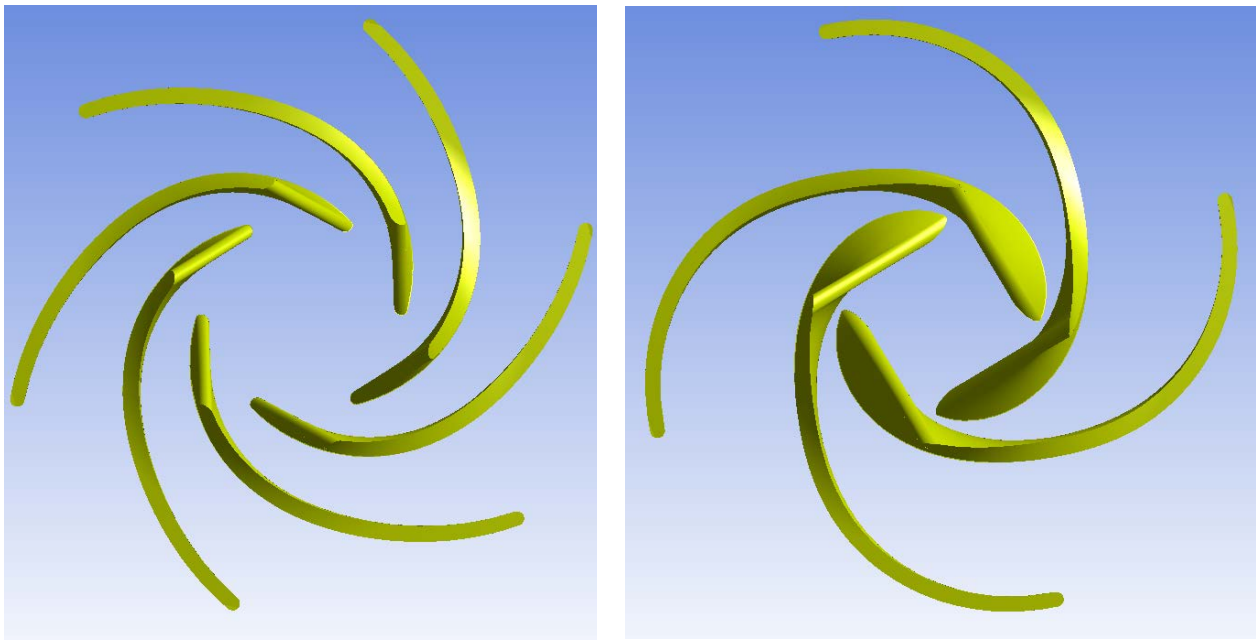


Figure 3. Distribution of geometrical parameters angle ϑ (blue) and θ (grey) in relation to the length l of the blade.

Figure 4. Geometry of the pump impeller blades obtained in ANSYS DM.

Comparing the geometry of the impeller obtained from analytical methods based on empirical models (Figure 4) with the original (Figure 5a) and the optimized (Figure 5b), we can see that the impeller has kept the same number of blades as the original one (Z = 6), but the blade wrap angle θ has been increased.



a) b)

Figure 5. Geometric model of the impellers:
a) the original impeller; b) the impeller with optimized blades

4.2. Forming the geometric model in ANSYS DesignModeler

Discretization of the pump impeller model was performed in ANSYS TurboGrid. This grid generator was chosen because it provides automated discretization [20] algorithms that can generate discretization grids for complex turbomachinery impeller geometries [21].

Figure 6 shows a grid created in ANSYS TurboGrid. The desired y^+ parameter equals to 1 and the Reynolds number of the fluid flow equals to $5 \cdot 10^5$ in the pump impeller. These settings were used to set the boundary layer's characteristics automatically. The application of ANSYS TurboGrid with the given parameters allows to obtain a sufficiently dense structured grid, including the boundary layer description, which is necessary for a proper description of the fluid flow. The discretization grid of the pump impeller obtained with $N_{R1} = 3 \cdot 10^6$ finite elements was obtained.

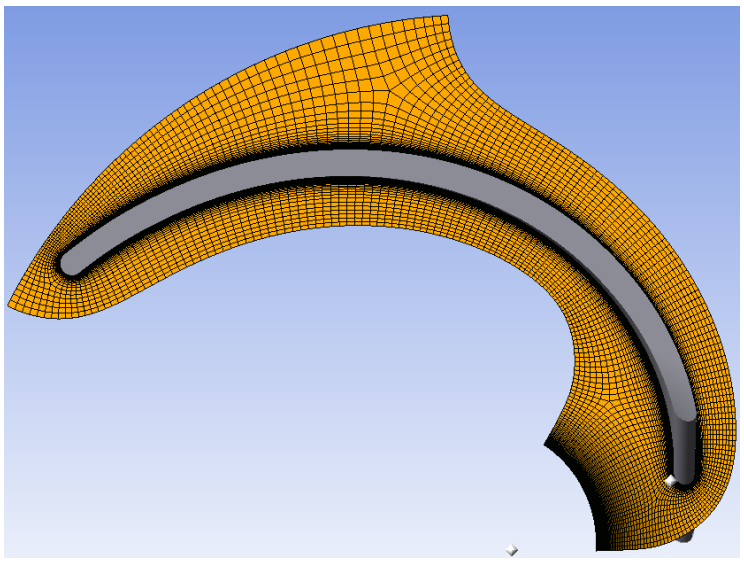


Figure 6. Structured discretization network obtained in ANSYS TurboGrid.

The ANSYS Meshing, a universal discretization environment, which thanks to its ease of representation is the most commonly applied grid generator used in ANSYS [21]. It was used to obtain the discretization grid of the suction connection and the pump casing volute.

In conducting the studies, the optimal discretization grid parameters were obtained in convergence studies from [21,22]. On the walls of the flow zone the finite element size of ΔS = 2 mm was selected, the inflation method with 20 inflation layers and the inflation layer thickness of 3 mm was applied. Also, in the case of the pump casing volute model on the area where the inflation method was applied, the sizing procedure with the finite element size of 1.25 mm was also applied. The discretization grid of the suction connection with $N_{S1} = 0.65 \cdot 10^6$ finite elements and the grid of the pump casing volute with $N_{S2} = 2.03 \cdot 10^6$ finite elements was obtained.

4.3. Flow simulation settings used in the study

The *Total Pressure* (P_{inlet} = 1MPa) is indicated at the pump **Inlet**, with a low turbulence state (1%). At the pump inlet the flow is completely formed of water in liquid form. The flow is considered isothermal (t = 25˚C), with zero reference pressure (P_{ref} = 0 atm).

At the **Outlet** of the pump casing discharge pipe, the *Bulk Mass Flow Rate*, (Q = 1.75 kg/s) is indicated. The flow characteristics related to turbulence and cavitation at the pump outlet are calculated with the Zero Gradient condition.

The impeller domain is required to run at 2950 min^{-1}. The SST (Shear Stress Transport) model [23] is used in the simulation to describe the turbulent flow, model being universal [21,24], which requires limited computational resources compared to transient models. Considering that the simulation is based on the two-phase continuous fluid model, the fluid consists of: *water in liquid form with a temperature of 25˚C and water vapors*. In the initial state the fluid consists of water in liquid form.

As a mass transfer model, the Zwart - Gerber - Belamri model [25] is applied. The following calculation characteristics were applied: vapor saturation pressure – 3170 Pa and mean bubble diameter – $2 \cdot 10^{-6}$.

As a *Timescale Control* model, the *Physical Timescale* option was selected, with time step equal to $1/\omega$ = 0.003237s.

4.4. Setting processing parameters

As a stop computation condition the following was selected: either the final number of 1000 computation iterations or the condition when the residual error tolerance of 10^{-5} was reached during the simulations. In order to monitor the convergence, the following indicators were selected: static and absolute pressure at inlet and outlet, as well as torque with respect to the rotation axis applied to the pump impeller. From Figure 7 we can see that the calculation is convergent.

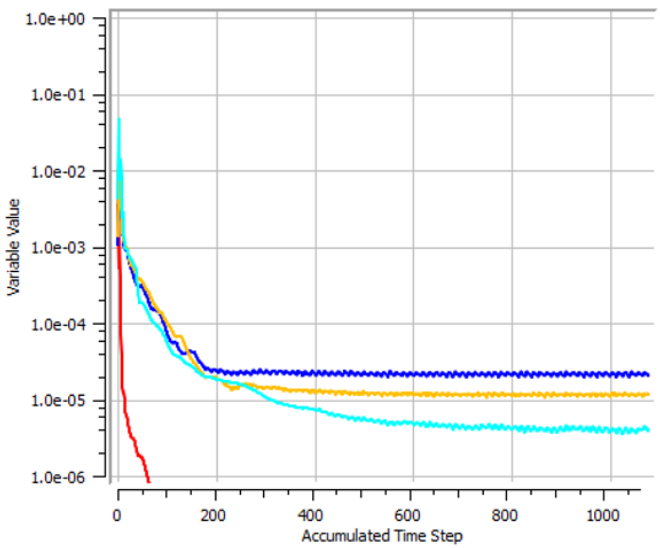
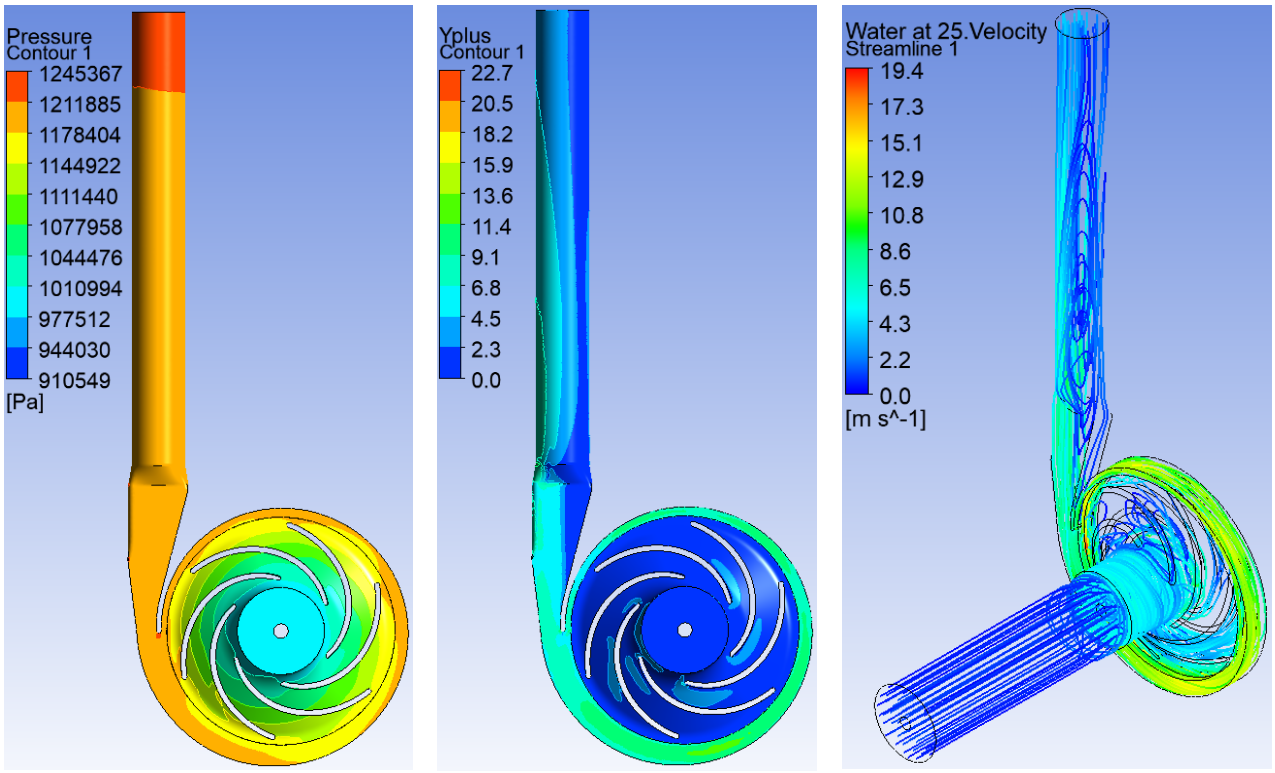


Figure 7. Root mean square errors.

4.5. Analysis of the obtained results

The simulation of the pump's impeller flow zone was performed. The simulation results are shown in Figure 8.



a) b) c)

Figure 8. Flow simulation results in the flow zone of the pump with impeller obtained by analytical calculation: a) pressure field distribution; b) y^+ parameter values distribution; c) streamlines showing flow velocity.

The comparison of the characteristics of the pump with impeller geometrical parameters obtained by analytical calculations, with original one and with optimized impeller obtained by coupling CFD calculations and optimization algorithms are shown in Table 3.

Table 3

Comparison of the pump's impeller characteristics

Impeller geometry	Pumping load, mH_2O	Torque, Nm	Impeller efficiency	Pump efficiency
Original	20.8	2.03	0.56	0.363
With optimized blades	19.9	1.776	0.619	0.396
Analytically calculated	21	1.91	0.6	0.384

The highest efficiency was obtained by the impeller with optimized blades η_{rot}= 61.9%, but the impeller obtained by analytical calculations η_{rot} = 60%, also shows superior characteristics to the original one. We can also see that the analytically calculated impeller presented the highest pumping head of all the presented impellers, but within the allowed limits.

5. Conclusions

The theoretical considerations on centrifugal pumps have been presented in the paper. We can see that, although over the years we can notice a significant progress in theory, the empirical computational models are losing to optimizations based on CFD simulations and optimization algorithms, but can be used as a benchmark in an optimization process.

The calculation based on the empirical model of the geometrical parameters of the centrifugal pump impeller was carried out and compared with the optimized geometrical model. We can see that the highest efficiency was obtained by the impeller with optimized blades η_{rot} = 61.9%, but the impeller obtained by analytical calculations η_{rot} = 60%, which is higher compared to the original impeller η_{rot} = 56%.

Conflicts of interest: The authors declare no conflict of interest.

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COMPARISON AND EVALUATION OF CLASSICAL METHODS OF DIMENSIONAL CHAINS THEORY AND THEIR MODERN ANALOGUES

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Abstract. The requirements for the quality, reliability, and cost-effectiveness of engineering products and engineering production itself are constantly improving. As a result, there is an increasing demand for the quality of design and technological preparation of production, which includes classical dimensional analysis as its foundation. The Classical Method of dimensional analysis calculation represents a comprehensive set of computational and analytical actions carried out during the development and analysis of projects and technological processes, including: the construction of specialized dimensional diagrams for projects and technological processes, the identification and recording of interconnections between all dimensional parameters, the identification of dimensional chains, verification, and the establishment of rational sizing methods in drawings. Dimensional analysis involves a significant number of procedures and actions. The time required for dimensional analysis is substantial, ranging from 10 to 50 hours for a single technical drawing or technological process. At the same time, the use of Modern Methods for calculating dimensional chains will allow us to determine, after a thorough evaluation of manufacturing conditions at each production stage (operation), leading to a reduction in the manufacturing cost of parts. The increased workload of the evaluation process can be compensated by using databases and appropriate software that operates interactively with the user. This will also lead to a reduction in the labor intensity of dimensional analysis of projects and technological processes through automation.

Keywords: *calculation of tolerances, classical methods, simulation, modern programs, tolerance analysis, tolerance limit.*

Rezumat. Cerințele de calitate, fiabilitate și rentabilitate pentru produsele inginerești și pentru producția inginerească în sine sunt în mod constant îmbunătățite. Ca rezultat, există o creștere a cererii pentru calitatea proiectării și pregătirii tehnologice a producției, care include analiza dimensională clasică ca fundament. Metoda clasică de calcul a analizei dimensionale reprezintă un set cuprinzător de acțiuni computaționale și analitice efectuate în timpul dezvoltării și analizei proiectelor și proceselor tehnologice, incluzând: construcția diagramelor dimensionale specializate pentru proiecte și procese tehnologice, identificarea și înregistrarea interconexiunilor dintre toți parametrii dimensionali, identificarea lanțurilor

dimensionale, verificarea și stabilirea metodelor raționale de dimensionare în desene. Analiza dimensională implică un număr semnificativ de proceduri și acțiuni. Timpul necesar pentru analiza dimensională este semnificativ, variind de la 10 la 50 de ore pentru un singur desen tehnic sau proces tehnologic. În același timp, utilizarea metodelor moderne de calcul a lanțurilor dimensionale permite o evaluare minuțioasă a condițiilor de fabricare la fiecare etapă de producție (operațiune), ceea ce conduce la o reducere a costului de fabricare a pieselor. Volumul crescut de lucru al procesului de evaluare poate fi compensat prin utilizarea bazelor de date și a software-ului corespunzător care funcționează interactiv cu utilizatorul. Acest lucru duce, de asemenea, la reducerea volumului de muncă a analizei dimensionale a proiectelor și proceselor tehnologice prin automatizare.

Cuvinte cheie: *Calculul toleranțelor, metodele clasice, simularea, programele moderne, analiza toleranței, limita toleranței.*

1. Introduction

Dimensional analysis of structures is a crucial stage in the dimensional advancement of structures, as it allows you to identify the relationship of components and assembling units that make up the machine, determine methods for achieving the required accuracy of the machine, analyze the correctness of setting dimensions and tolerances on the drawings, improve the manufacturability of the design, establish the sequence of assembly of the machine and its assembly units, Figure 1 [1].

The purpose of dimensional analysis is to ensure the quality and manufacturability of products, their elements, workpieces, obtain the dimensions and maximum deviations necessary to fill in technological maps, setup sketches, control programs, calculate cutting conditions, time standards.

Dimensional analysis of assembly is a set of calculation and analytical procedures executed in the development and analysis of assembly and technological methods of machining, including: construction of special dimensional schemes of technological processes; identification and fixation of the relationships of all dimensional parameters, including the use of graph theory; identification of dimensional chains of structures and technological processes; confirmation and establishment of rational ways of sizing in the drawings; assignment ample and necessary amount of technical specifications; nominations of reasonable parameters, the minimum required benefits; verification estimation of the possibility of ensuring drawing dimensions and technical requirements; calculation of

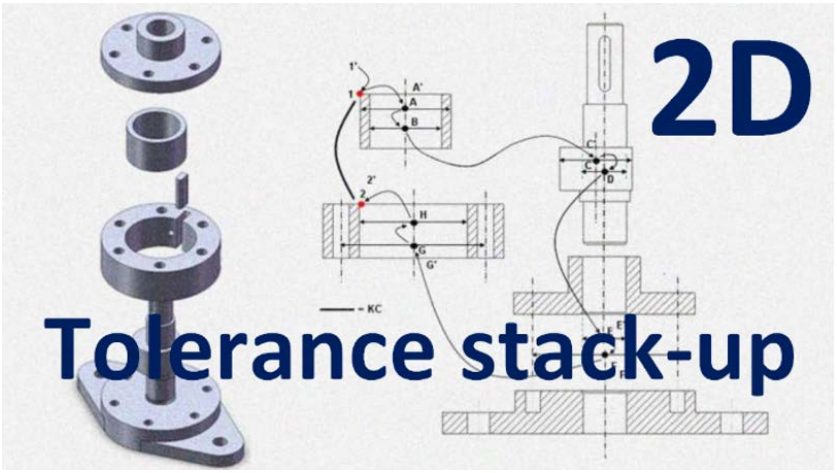

Figure 1. Tolerance stack-up Example [1].

average and minimum allowances; determination of nominal values of operating dimensions; calculation of coating depth, nitriding thickness and other parameters.

Dimensional analysis involves many actions. The complexity of dimensional analysis is very significant - dimensional analysis of one design or one technological process can take from 10 to 50 hours.

The solution to the problem of reducing the complexity of the dimensional analysis of machines and technological processes is possible based on its automation. In mathematical modelling of dimensional chains of assembles and technological processes, graph theory is used, which makes it possible to connect theoretical positions with computational algorithms implemented on a computer. The most advanced methods for automated calculation of operating dimensions, location deviations based on dimensional chains are the methods proposed by Ivashchenko [2], Mordvinov et al. [3], Smetanin et al. [4] and several other authors.

Their main advantage is a reduction in time and an increase in the quality of design; The main disadvantage is the need to generate dimensional schemes and graphs in manual mode, which makes it difficult to implement these techniques in production (Figure 2) [5].

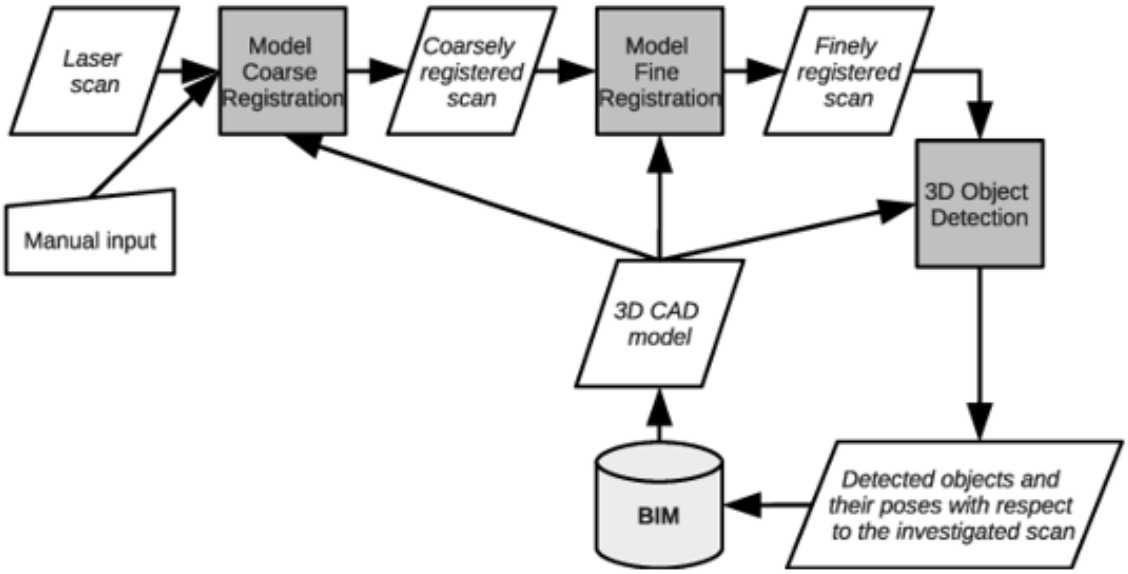

Figure 2. The process of studying 3D elements of the model using laser scanning [5].

A more advanced technique is the "Tolerance Analysis" [6] module in Autodesk Inventor (Figure 3).

The advantage is that it is not necessary to build dimensional schemes, but it is very laborious due to the need to calculate and organize digital and graphic data that are manually entered using special “windows” to be able to perform the calculation. To automate the dimensional analysis more fully, a computer program “Tolerance Tools” has been developed [6].

The solution of variants of one problem provides for the possibility of using the originally entered information for multiple repetition of the solution when the calculation conditions, the utility of dimensional parameters, or a minor change in the composition of operations in the checklist of initial datasheet change.

To ensure ease of coding, information about the assembly unit, part, workpiece, and technological process of machining is presented in the form of geometric models that have only flat and cylindrical surfaces.

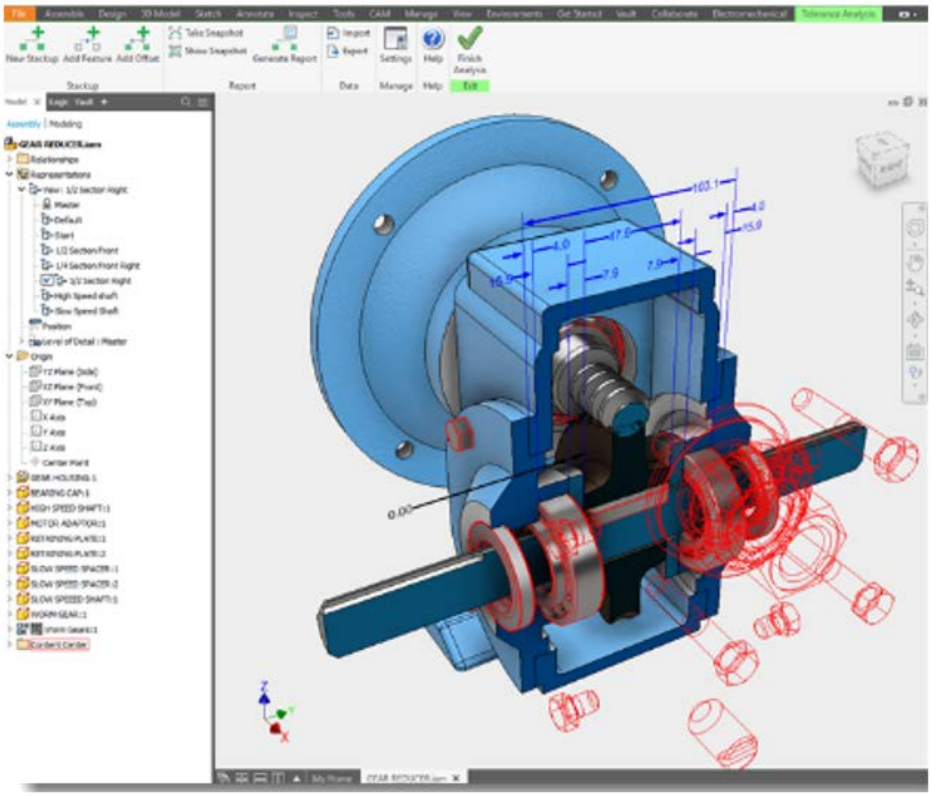

Figure 3. "Tolerance Analysis" module in Inventor [6].

2. Classical methods the theory of dimensional chains and analysis

When designing mechanisms, machines, instruments, and other products, designing technological processes, choosing measurement tools and methods, and operating products, it becomes necessary to conduct a dimensional analysis, with the help of which the correct ratio of interrelated dimensions is achieved and permissible errors (tolerances) are determined. Dimensional analysis is performed using the theory of dimensional chains [7,8]. A dimensional chain diagram is an equivalent of interrelated dimensions that form a closed contour and determine the optimal position of the surfaces or axes of one or more parts. Dimensional chains diagrams graphically in the form of graphs (Figure 4).

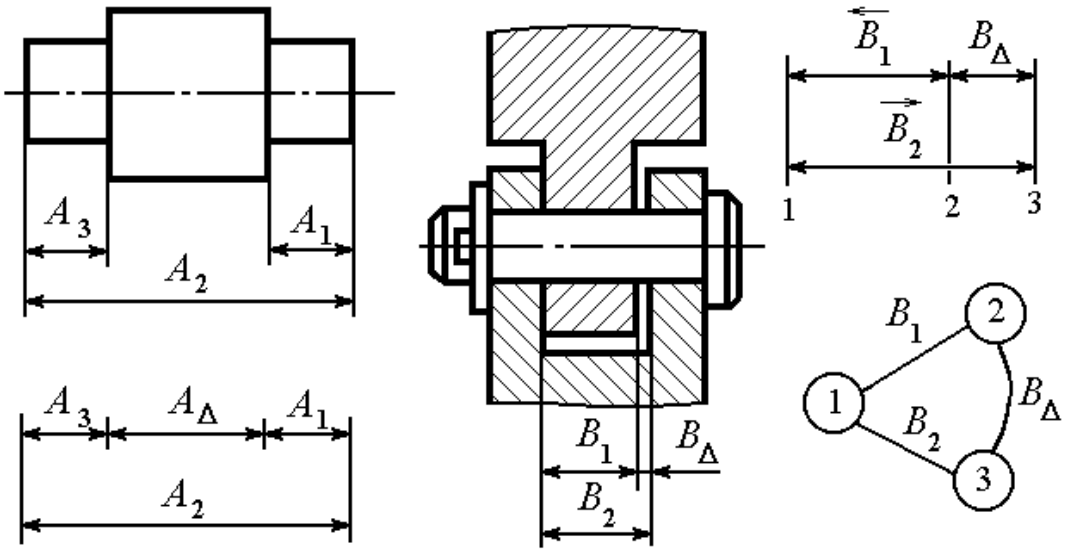

Figure 4. Example of a dimensional chain diagram, graph schema [7].

The dimensions that form a dimensional chain are called its links. The links of the dimensional chain can be any angular or linear parameters: diametrical dimensions, distances between surfaces (axes), gaps, tensions, overlaps, variance in the shape and position of axes, etc.

All dimensional chains consist of two or more links, one of which is closing, the rest are components. The link is called the closing link, to which the basic requirement of accuracy is imposed, which determines the quality of the product in accordance with the specifications.

To perform dimensional analysis, in addition to the dimensional scheme, an equation of dimensional chain is constructed, derived from the condition of closure Eq. (1):

$$c_1A_1 + c_2A_2 + ... + c_{m+}n + Am_{+n} = 0 \quad (1)$$

where:

$A_1, A_2, ..., A_{m+n}$ – the nominal values of all links in the dimensional chain;

c_1, c_2, ..., c_{m+n} – the coefficients that characterize the degree of influence of a link's variation on the change of the closing link, or the transmission ratios.

In dimensional chains with parallel links (linear chains) Eq. (2):

$$|c_1| = |c_2| = ... = |c_{m+n}| = 1 \quad (2)$$

In planar and spatial dimensional chains (general case) Eq. (3):

$$c_i = \frac{\partial A_\Delta}{\partial A_i} (i = 1, 2, ..., m+n) \quad (3)$$

If a growth in the constituent link leads to a growing in the closing link, the transmission ratio is positive; if it leads to a decrease, the transmission ratio is negative.

2.1. Problems solved using dimensional chains

The calculation of dimensional chains is necessary when solving the problems of designing, manufacturing, and operating a wide class of products (machines, mechanisms, instruments, devices, etc.). Using the theory of dimensional chains, the current design, technological issues can be solved:

- Establishment of geometric and kinematic connections between the dimensions of components; calculation of nominal dimensions, variances, and dimensional tolerances.
- Calculation of precision standard and formulation of requirements for machinery and their parts.
- Analysis of the correctness of sizing and parameters on the current datasheets of parts.
- Determination of interoperation parameters and tolerances.
- Justification of the order of technical processes in the production and assembly of parts.
- Rationale and computation of the required precision of fixtures.
- Choice of means and techniques of measurements, calculation of achievable measurement accuracy.

A complete calculation of dimensional chains is carried out in the process of developing the working design of the machine, preliminary calculations should be made during the constructive development of the technical design. All issues resolved through the assistance of dimensional chains are divided into two types: direct and inverse. direct

task. According to the calculated value and the tolerance or deviations of the master link, the basic values, tolerances, maximum deviations of all the constituent links of the dimensional chain are determined. Such a task relates to the design calculation of a dimensional chain. Reverse problem.

According to the established nominal values, tolerances and maximum deviations of the constituent links, the standard value, tolerance, and maximum deviations of the closing loop are determined. Such a task refers to the verification calculation of the dimensional chain.

The main task is direct, since it allows solving the main problem in the design of the machine - to determine the parameters of the constituent links that ensure the accuracy of the closing link of the machine or part.

The inverse problem is solved if it is needed to check the correctness of the conclusion of the direct issue or those accepted without calculating dimensions and tolerances.

2.2. Full interchangeability method and maximum-minimum method

The method has significant advantages, including simplicity, clarity, low computational workload, a complete guarantee against defects due to inaccuracies in the mating link, and the absence of the need to allow for even a small percentage of risk in the calculations.

The use of this method will allow us to obtain:

- simple and cost-effective assembly.
- the possibility of organizing in-line assembly.
- the possibility of wide cooperation between industries.
- the simplicity of manufacturing spare parts and supplying them to consumers.
- the possibility of selective control.

Scope - in large-scale and mass production, with a small tolerance of the closing link and a small number (up to five) of the constituent links of the dimensional chain, with multi-link dimensional chains with a large tolerance for the closing link. The disadvantage of the method is that the tolerances of the constituent links are smaller, all other things being equal, than with all other methods, which may turn out to be uneconomical. If the accuracy of the closing loop of the dimensional chain is achieved by the method of complete interchangeability, then the calculation of dimensional chains using the maximum-minimum calculation method is applied, Figure 5 [8].

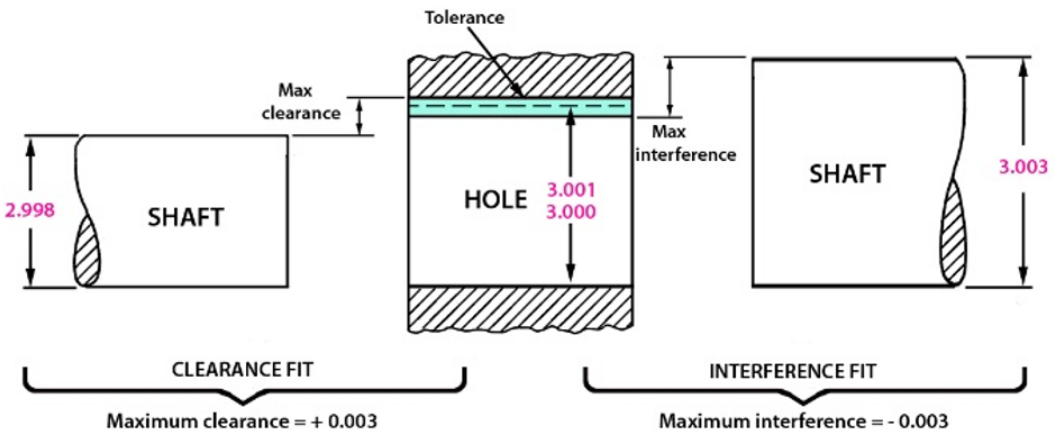

Figure 5. Maximum-minimum deviations [8].

The maximum-minimum method assumes that the assembly receives parts with limiting dimensions in combination, in which all increasing links will be the biggest limiting dimensions, and reducing links will be the minimum ones. Therefore, the parameter of the closing loop will be max or min, the likelihood of which is very minor.

The method leads to large margins of accuracy, and the calculated tolerance values obtained by this method often do not correspond to the specified ones. If we proceed from the tolerance of the closing link, then the tolerances of the constituent links turn out to be unnecessarily tight. If they proceed from the tolerances of the constituent links, then the calculated tolerance of the closing link is greater than the specified one.

This method has great benefits - simplicity, clarity, low complexity of computational work, a full assurance against marriage due to the inexactness of the closing loop, no necessity to permit even a minor degree of uncertainty in the calculation.

The maximum-minimum method is financially viable only for Dimensional chains with a small number of precise component loops. In other cases, the required precision in the manufacture of parts may go beyond not only economic, but also practically achievable accuracy.

The method should be used to solve design and verification problems in the terms of single-unit and small-scale fabrication of products, in the design of single component, for initial calculations of an ancillary aspect, and in cases where even a negligibly small chance of the closing link parameters going beyond the permissible limits is unacceptable [9].

2.3. Group interchangeability method

Parts are connected without fitting and regulation. The calculated value of the tolerance of the component link increases several times to an economically viable manufacturing tolerance.

After manufacturing, the parts are sorted according to their actual dimensions into groups within the design tolerance and are assembled into the corresponding groups using the method of complete interchangeability. It is possible to achieve high accuracy of the closing link with appropriate tolerances of the component links.

The scope of application is mass and large-scale production with small-link (3-4 links) dimensional chains with high accuracy of the closing link.

The disadvantages of the method are an increase in the volume of work in progress, additional costs for checking, sorting, and marking parts, and some complication in the supply of spare parts.

The calculation of dimensional chains using the group interchangeability method can be carried out using the maximum-minimum method or the probabilistic method.

The calculation includes the replacement of the design tolerances of the constituent links with production or technological tolerances, which may exceed the design tolerances by several times.

To ensure the necessary precision of the closing loop, the component links are sorted into groups according to actual sizes, and the scatter field of the sizes of each group must be equal to the design tolerances of the component links.

2.4. Fitting method

The required accuracy is achieved through the fitting of a pre-designed component called a compensator, onto which a specific allowance is applied during mechanical processing for assembly.

It ensures the possibility of achieving high precision in the closing link while maintaining economically feasible manufacturing tolerances for the constituent links.

Application area: single and small-scale production, multi-link dimensional chains with a high-precision closing link.

Disadvantages of the method: significant increase in assembly cost and time, difficulty in standardization and mechanization, complexity in production planning.

It provides the ability to adjust the closing link not only during assembly but also during operation, as well as the possibility of automatic adjustment of precision [10].

Application area: all types of production requiring high precision in chains.

Disadvantages of the method: potential complexity in product design, increased number of components, and assembly complications due to the need for adjustment and measurements.

3. Modern analogues of dimensional chains and analysis

Nowadays, most of the production process is devoted to reference literature: quality standards, tables, etc. As a result, it takes a long time to launch a new part or machine into production. This situation is unacceptable from the point of view of economic competition and in the conditions of the rapid development of society and technology. In addition to general computerization and automation, but also the increasing use of computer technology, not only the problem of digitizing reference information, but also the problem of developing programs for managing this information is becoming increasingly relevant.

Debugging and replacing some algorithms with others, depending on the production conditions and the development of methods for calculating dimensional chains, Figure 6.

Computer-based simulation utilizing contemporary software - Tolerance Tools

Autodesk® Inventor® Tolerance Tools is a special addon, the one-dimensional tolerance tools software aiding in gaining a better insight into the influence of mechanical fit and performance through the combined dimensional changes, Figure 7. A one-dimensional tolerance stack-up Implies that the distance under examination, along with all contributing dimensions affecting its modification, are aligned in one vector direction.

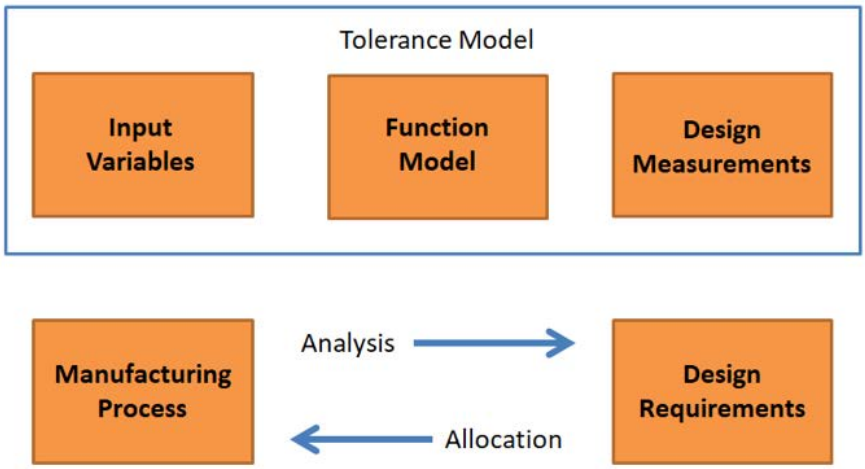

Figure 6. Methods for calculating dimensional chains.

One vector modification of the plane along the stack-up direction is constant; angular modification of the plane concerning of other is not measured. At times, the impacts of angular modification are disregarded, that it is crucial to validate the analysis.

The aim of tolerance design is to account for the permissible modification in every part to ascertain whether the engineering demands are fulfilled during assembly. Tolerance analysis aids in achieving the following: ensuring fits better excluding the necessity for manual calculations and tables, determining the optimal tolerances this will allow us to minimize fabrication costs, enhancing the requirement quality, and finishing of your final product.

Tolerance Analysis tool sustains of Worst Case method (Figure 8), the individual parameters are placed at any of the maximum, or minimum deviations to make the stack up distance as bigger or as smaller as admissible (Figure 9), general Statistical (Figure 10), and Root of the Sum of Squares method (Figure 11).

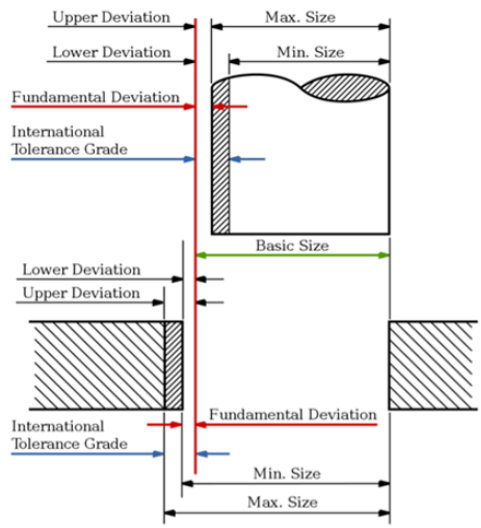

Figure 7. Tolerance Deviations and Sizes [11].

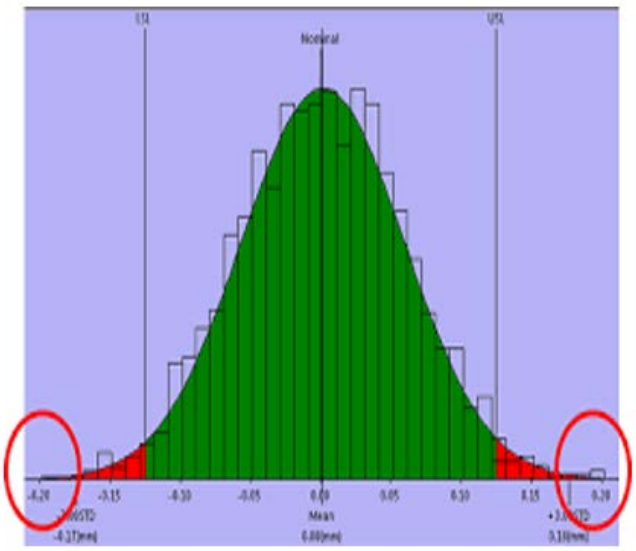

Figure 8. Worst Case method [12].

The Worst Case method does not including the deviation of the individual parameters. As an alternative, it presupposes that - all components have been manufactured at the maximum allowable limit of acceptance to bring in to assemble. Worst Case method forecast the utter upper and lower limits of the stack up distance.

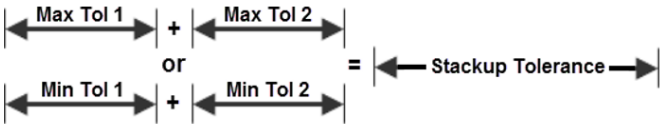

Figure 9. Components of overlay tolerance [13].

The standard variation computed for the normal distribution of each parameter is derived from equation Eq. (4):

$$C_p = \frac{UTL-LTL}{6\sigma} \tag{4}$$

From where:

- UTL – Upper Tolerance Limit;
- LTL – Lower Tolerance Limit;
- σ – standard variation distribution.

Solving by the standard variation yields Eq. (5):

$$\sigma = \frac{UTL-LTL}{6*C_p} \quad (5)$$

The modest pretense of C_p=1.0 stems from the assumption of a fabrication process that places the variation of tolerances at +/- 3 standard variation from center line of the tolerance area, this is assumed to be the average, so that the possibility of a part respect the necessary tolerances is 99.7 %.

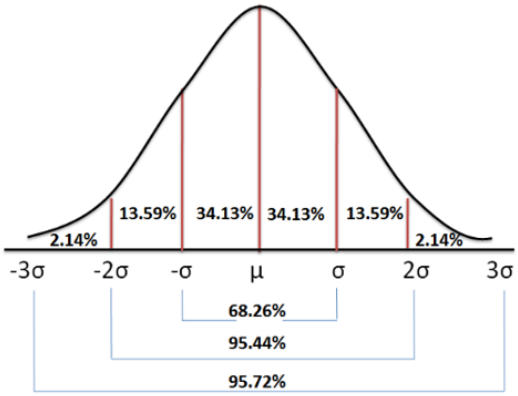

Figure 10. Statistical Method [14].

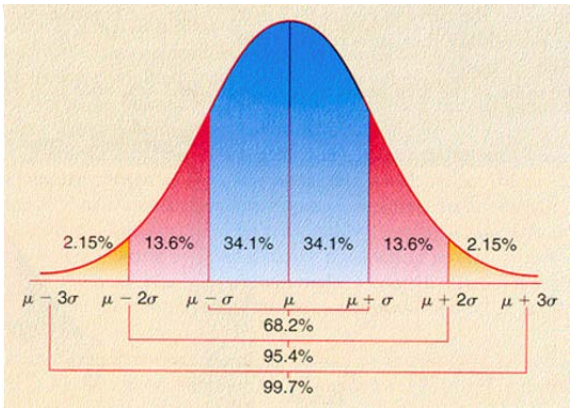

Figure 11. Root Sum of Squares Method [14].

Tolerance Analysis assumes, for all statistical evaluations, that manufacturing aims for the center line of the tolerance area. As a result, that mean is at the center line of the tolerance area. Root of the Sum of Squares analysis applies the principles of the statistical analysis method relate to the previous component but with certain clarify assumptions to facilitate computations using tolerances such as standard variations [15].

The main presupposition is that the proportions of each tolerance, to their respective standard variations on the dimension and the stack-up outcome became an equal. For a Root of the Sum of Squares method, Tolerance Analysis suppose a C_p of 1.0 for all parameters and the develop stack up limits.

4. Conclusions

Dimensional analysis of projects and technological processes represents a set of calculation and analysis procedures carried out during the development and analysis of machining:

- Construction of special dimensional diagrams for technological processes.
- Identification of dimensional chains in projects and technological processes.
- Assignment of reasonable tolerances and necessary minimum reserves.
- Calculation of average and minimum reserves.

Dimensional analysis involves a significant number of procedures and actions. The time required for dimensional analysis is substantial, ranging from 10 to 50 hours for a single technical drawing or technological process. Reductions in the labor intensity of dimensional analysis.

Conflicts of interest: The author declares no conflict of interest.

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TECHNOLOGICAL TRANSFER UNDER THE CONDITIONS OF DIGITALIZATION OF PRODUCTS AND PROCESSES

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Abstract. Technological development is largely determined by technology transfer, which is conditioned by the absorption capacity of new technologies, and new technologies are deeply digitized technologies. Success depends on creating basic digital skills, both technical and human, developing digital infrastructure, ensuring accessibility to digital technologies. In the context of Industry 4.0 technologies, the efforts to design products with pronounced physical-cybernetic elements are important, but especially those aimed at creating digital twins, gradually moving from intermediate variants of digital model and digital shadow. Digital twin creation models refer to the life cycle with emphasis on its stages. The paper proposes a digital twin model based on the technological function, in which the modification of the properties is manifested by restructuring the internal functions of the operator, operand and interface. The central place in this model belongs to the interface, which reflects the multitude of physical-technical processes at different scales of macro, meso, micro analysis characteristic of objects and processes in machine building.

Keywords: *technological transfer, industry 4.0, digital model, digital shadow, digital twin, technological function, technological interface.*

Rezumat: Dezvoltarea tehnologică este determină în mare măsură de transferul tehnologic, care este condiționat de capacitatea de absorbție a noilor tehnologii, iar noile tehnologii sunt tehnologii profund digitalizate. Succesul depinde de crearea competențelor digitale de bază atât tehnice cât și umane, dezvoltarea infrastructurii digitale, asigurarea accesabilității la tehnologiile digitale. În contextul tehnologiilor Industriei 4.0 importante sunt eforturile de proiectare a produselor cu elemente pronunțate fizico-cibernetice, dar mai ales cele orientate spre crearea gemenilor digitali, trecând treptat de la variante intermediare de model digital și de umbră digitală. Modelele de creare a gemenilor digitali se referă la ciclul de viață cu accentele pe etapele acestuia. În lucrare se propune un model de geaman digital bazat pe funcția tehnologică, în care se manifestă modificarea proprietăților prin

restructurarea funcțiilor interne a operatorului, operandului și interfeței. Locul central în acest model aparține interfeței, care reflectă multitudinea de procese fizico-tehnice la diferite scări de analiza macro, mezo, micro caracteristice obiectelor și proceselor din construcția de mașini.

Cuvinte cheie: *transfer tehnologic, capacitate de absorbție, industrie 4.0, digitalizare, model digital, umbră digitală, geamăn digital, funcție tehnologică, interfață tehnologică.*

1. Introduction

All industrial revolutions resulted in the formation of leading and following economies, depending on their involvement in the creation and use of the emerging technologies characteristic of the revolutions. It can be seen that an important part of the world's countries remained outside the ongoing revolutions every time. Only after several decades does the gap close after the technologies become cheap enough. It is considered that there are about 30 developed countries, about 80 developing countries, including the Czech Republic, Hungary, Poland, Bulgaria, Romania, etc., and the rest - poorly developed, including the Republic of Moldova. This classification is important from the point of view of the development potential. The desire for development, including through technological transfer, must be supported by capacities to absorb new technologies, capacities that must be prepared technically-technologically (technoware), organizationally (orgware), informationally (infoware) and humanly (humanware). However, these capacities remain very different in today's modern world, even in the context of the digitization of economies.

According to the report of the United Nations Industrial Development Organization (UNIDO) for the year 2020 [1], in the field of advanced digital production technologies only ten leading economies (United States of America, Germany, Japan, China, Taiwan Province of China, Switzerland, France, United Kingdom, Republic of Korea and Netherlands) account for 90% of patents and 70% of digital technology exports. Another 40 economies follow (the followers), but with much lower values in the research/development and commercialization of digital technologies. Developing countries have technologies and technological systems characteristic of the Industrial Revolution 3.0 (3IR), sometimes in incomplete versions, and modernize to transform them according to the Industrial Revolution 4.0 (4IR).

The lack of capabilities to master the basic automation of 3IR technologies and information and communication technologies also makes it difficult for them to fully exploit the opportunities of advanced digital manufacturing technologies. The main challenges and opportunities for developing countries consist in the gradual integration of advanced digital technologies within the existing 3IR manufacturing systems, the modernization of production systems in the aspects where informational integration is possible. Other countries either have less activity or fail for various reasons to take part in the creation and use of these technologies.

It is found that a good part of the companies is still in the conditions of analog production. The transition to 4IR technologies depends on the conditions of the country and its industry. A key issue for countries where the majority of production is predominantly in the analog domain is how they can move up the technological ladder. Massive digital openness through non-industrial tools means that companies can skip a few generations or go straight to the most advanced ones. The differences between capabilities, endowments

and technological efforts, between organizational characteristics and internal infrastructural and institutional conditions not only explain why some companies and countries manage to climb the digital ladder of technologies, but also demonstrate that advancement is possible [1]. The objective conditions of development, the effects of the scale of industrial factors, the effects of the state economic development policies of the Republic of Moldova place the country in the category of laggards, but the appropriate conditions for the adoption of these technologies by industrial companies can stimulate inclusive and sustainable industrial development and the achievement of the objectives of sustainable industrial development.

In the process of technological development in the machine building eterprises through transfer or through own research-development support, the perspectives opened by this Industry 4.0 concept will be taken into account. The perspectives are channeled by six design principles: decentralization, virtualization, modularity, interoperability, service orientation, real-time capability [2].

The pillar technologies of Industry 4.0 are determined by scientometric tools. In the paper [2], the following key technologies of Industry 4.0 are specified (Figure 1): autonomous and collaborative robots, augmented reality (AR), simulation/digital twins, horizontal and vertical integration, cyber security, the Industrial Internet of Things (IIoT), cloud computing, big data analytics. Artificial intelligence (often mentioned together with big data analytics), cloud manufacturing, M2M (direct communication between machines, devices) can be added to this list.

One of the most promising technologies of the Industrie 4.0 concept with an impact on the tasks to be achieved for engineers in the field of machine construction is the technology of simulation and digital twins. The reason is simple. Modeling and digital twins refer to products, processes, phenomena in the mechanical field, namely researchers in this field can solve the situations.

Research related to the creation and augmentation of digital twins is very intensive and covers several areas such as: product design [3, 4], assembly processes [5], mechanical manufacturing processes and through additive technologies [6, 7], mechanical machining [8-10], CNC machine tools [11, 12], cutting tools [13], materials [14], tribological phenomena [15] and others.

2. Technological transfer in the current industrial conditions in the Republic of Moldova

According to UNIDO, the industrial development of a country can be evaluated by the industrial capacity index [16]. Industrial capabilities represent the collective and personal skills, productive knowledge and experiences accumulated by industrial agents and companies to perform various productive tasks, absorb new technologies and coordinate production along the supply chain. The index of industrial capacity can be taken as a rough indicator of the basic capacities of countries in the field of production, which combines three dimensions: the ability to produce and export manufactured products, technological deepening and modernization and the global and/or regional impact.

The capacity to produce and export products manufactured by RM companies is low. The large and inefficient post-Soviet companies have been liquidated, and the new and modern ones are still few and, as a rule, small and medium. Technological deepening and modernization is focused on computer-aided design, CNC technologies, 4G communications

with the near prospect of 5G, etc. and does not have a systemic character, but an insular one. The improvement of the situation on all three components can be achieved by realizing the path of European integration, through internal and international industrial collaboration. Thus, the industrial visibility of companies from the Republic of Moldova may be increasing, initially mediated by partners from developed and developing countries, then directly.

The development of car manufacturing companies operating in the Republic of Moldova is largely determined by technological transfer through direct foreign investment. Thus, branches of several companies from industrially developed countries such as: Italy, Belgium, Holland, Germany, Romania, USA, Spain, France etc. have been opened recently.

The activity of these companies is focused on product design and manufacturing. However, the emphasis is on design, so that the transfer of advanced digital technologies occurs through the human factor to the extent that the parent company is involved in the modernization of its own technologies. Some gap can be observed, but the use of licensed CAD/CAE/PDM/PLM computer programs, often from the servers of companies in developed countries, working in project teams, products designed according to the requirements of customers in industrially developed countries produces effects comprehensive digital. Smaller in scope are the manufacturing activities, but also in this field the corporate technological transfer related to the use of CNC programmable machines and licensed CAPP/CAM computer programs is positively manifested.

Industrial companies in the field of machine building face several challenges, which can also become great opportunities for the implementation of advanced digital technologies. Among them can be listed the basic capabilities, the modernization and integration of technological resources, the modernization of the digital infrastructure, overcoming the digital capacity gap, access to technologies and their accessibility [1].

1. *The basic capabilities*. The basic capabilities needed to absorb and implement advanced digital technologies are different for design and manufacturing companies. The design not only defines the functional-constructive structure of the object in question, but also determines the manufacturing and operating conditions, informationally determines the participants of the supply chains, etc. The product design serves as a major requirement, as a starting point for manufacturing. Manufacturing is more complex, because it gives a functional answer to the project requirement, the effort is physically multiplied by the value of the series, by the complexity of the product and its components. In manufacturing, the de facto participants of the supply and value chains manifest themselves physically and informationally. Thus, it becomes necessary to integrate new technologies with existing ones in complex technological systems.

2. *Modernization and integration of technological resources*. Design companies invest actively in new versions of computer programs and new applications. Computer programs, being the result of competition between software producers, are increasingly coherent and mutually compatible. The new versions of the programs are integrative (CAD/CAE/PDM/PLM), cover multiple needs with reference to engineering objects and processes and offer great possibilities for digitization through digital twins. Manufacturing companies already have older technology resources adopted and need to invest and learn how to modernize and integrate new digital manufacturing technologies into the already existing technology system. Front-end replacement of obsolete analog machinery and equipment with digital ones is expensive and rarer, because it requires significant

investments and radical changes. CNC numerical programming and CAPP/CAM computer programs are easier to access and assimilate, because they increasingly represent integrated product-process CAD/CAE/CAPP/CAM/PDM/PLM systems.

3. Modernization of the digital infrastructure. The new 4IR technologies require a substantial reliable and secure information and communication infrastructure to ensure real-time design and manufacturing. 4G resources are sufficient for the current state of communication needs. The 5G perspective is an imminently necessary one, especially for manufacturing companies with the multiplication of information flows characteristic of it through the use of physical-cybernetic technical systems (machines, equipment, instruments, measurements, products and components in progress, sensors, etc.) generators and users of processed and structured information.

4. Overcoming the digital capacity gap. Companies from developed and developing countries are persistently engaged in activities with advanced digital technologies. These islands of 4IR technologies may be surrounded by partner companies still using older technologies. Thus, there is a brake in the activities of leading companies and a danger of losing the competitive battle for companies with weak digital capabilities. If this digital capabilities gap is long-lasting and sufficiently extensive, the implementation of advanced digital technologies remains limited and insular. Moldovan companies in the field of design and those in the field of manufacturing with foreign capital are not susceptible to the formation of deep gaps, the activities being ensured by common computer programs with the basic companies and by corporate assistance. The major risk of a gap persists for domestic companies in the field of manufacturing, because they do not have enough modernization resources, both financial and properly qualified human resources.

5. Access to technologies and their accessibility. Advanced digital technologies represent major elements of intellectual property, so their dissemination represents a commercial act under conditions of rights protection. As a consequence, these technologies are effectively controlled by a limited number of countries, and their companies have non-commercial competitive advantages in its implementation and use. Companies from other countries rely on the import of these technologies under the conditions of dependence on the suppliers of hardware components and software applications. For local Moldovan companies, access and accessibility are imminently commercial, with the exception of open innovation or technological transfer situations supported by the state in the interest of all companies in the field or through projects. For Moldovan companies with foreign capital, access and accessibility have a corporate character and are ensured by the base companies. Practice demonstrates access and accessibility with a gap for companies in the field of manufacturing, digital manufacturing equipment is usually second hand. However, there is a tendency to improve these gaps.

The pandemic crisis situation of 2020-2021 has become an index not only of the usefulness of digital technological modernization, but also of the resilience of companies. Digitally advanced companies have organizationally restructured their activities, placing emphasis on results, on remote communication and not on presence and schedule [16]. In the field of industrial manufacturing, digitization and automation have become one of the major trends in technological innovation. The implementation of advanced digital technologies essentially influences all aspects of industrial development and profoundly changes the competitive advantages of companies.

All advanced digital technologies are constantly evolving. For companies from poorly developed countries (the Republic of Moldova) with low incomes, abundant learning is opportune, that is, the training of human factor's skills. The competences of the human factor become attractive for foreign companies that come with joint business projects and investments in computer programs, in technical insurance with computers, communication networks, CNC machines, new organizational versions of functioning are formed. Thus, the priority of education in the field of advanced digital technologies is established, which has the ability to launch technological transfer in various aspects. In companies from developing countries there are already digital applications that can be used as avenues for wider and deeper technology transfer.

The implementation of advanced digital technologies is a complex but real process. The given technologies are interdependent, so the frontal implementation of at least a few more closely connected technologies is required, or their implementation one by one with relatively delayed real positive effects. The current digital gap between companies is determined by the differences in size, capacities and availability, by the existence and operation of innovation and technological transfer support systems.

A special role in promoting modern technological transfer belongs to state structures, which must place more concrete emphasis on industrial innovation to stimulate the adoption of advanced digital technologies in engineering, to encourage investments in research/development and the diversification of industrial production with high added value, to increase the ability to respond to new product design and manufacturing requirements. Adequate technology transfer policies are needed to drive the deployment of advanced digital technologies while reducing the costs and risks associated with their adoption.

3. Technological transfer through the provisions of the Industry 4.0 concept

The concept of Industry 4.0 represents a complex immaterial object with a major influence on the development of technologies and on technological transfer. In figure 1, this concept of Industry 4.0 is represented schematically in interaction with technologies from the branch of machine construction. Intelligent manufacturing itself includes computer-aided design technologies, material object processing technologies and 4IR digital technologies.

For each of the Industry 4.0 technologies taken separately, the other technologies represent the external environment, and the own elements (the partial technologies) represent the internal environment. In the systemic approach it is stated that "the internal and external environment of the system are continuous (the environment, in general, is continuous, and the division into external and internal environment is relative)", "the components of the system and the system as a whole are subject to development laws (...acts and manifests jointly in order to achieve well-defined objectives) and "the external environment represents the system's environment of existence from where it gets its resources, and the internal environment - the life environment" [17]. It can be concluded that the interaction between two technologies takes place with the participation of the external environment consisting of other technologies, so that the technologies in the environment can and do become development interfaces. An initial technology under the influence of the technological environment manifested through interface technologies becomes updated technology (Figure 2). And, since any change in the technological

environment produces imbalance, a continuous systemic technological development is observed, caused and supported by the tools of Industry 4.0.

The modern development of machine building's traditional technologies is done through integrative phenomena and thanks to computer and communication successes. However, the essence of the characteristic and specific processes of different industries remains as substance, as core. In this way, the division of responsibilities of the fields of concrete industries, on the one hand, and the field of informatics and communication, on the other, takes place. The technologies mentioned in figure 1 are actually dual, containing both a processing tool and an instrumented object, but specific to the industrial branch.

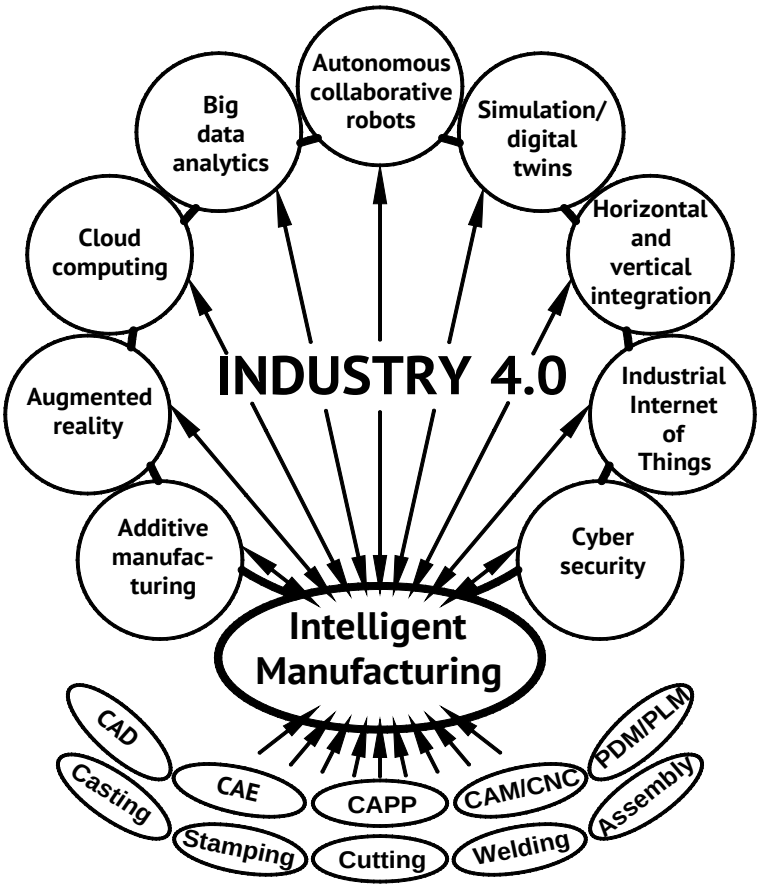

Figure 1. Intelligent manufacturing's technologies and tools.

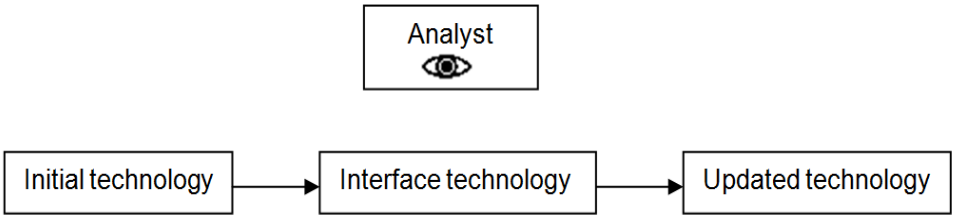

Figure 2. The development (updating) of technologies through interface technologies from the technological environment.

Both machine building and other industrial branches are represented in the new industrial concept by their own specific technologies. In the case of machine building, these technologies are: casting, molding, stamping, cutting, heat treatments, welding, assembly, etc. The essence of these processes is physical and technical. Operands are objects made of metal, of plastic, of composite materials etc. Operators are machine tools, equipment and

tools that ensure predominantly mechanical demands often assisted by energetic ones. The design and management of processes are increasingly computer assisted (CAD, CAE, CAPP, CAM, CNC, PDM, PLM, etc.).

4. Digitization - the basic factor of technological development in machine building

The pillar technologies of the Industry 4.0 concept are of different origins, but each of them essentially contributes to the informational integration of all processes. For any object or process, the integrating factor is the digitization of the its life cycle. In this sense, the "Simulation and digital twins" technology is of the greatest interest. The process of simulating and of creating digital twins is, in fact, a development of what in specialized literature is called Continuous Acquisition and Life-Cycle Support (CALS) developed in the USA in the 1990s.

The concept of a digital twin of existing physical objects or processes was proposed by Grieves in 2002 (University of Michigan) for product lifecycle management (PLM) and include the three elements [18]:

1. Physical object or process in a real space.
2. Virtual object or process with set of virtual subsystems in a virtual space.
3. Links through data and information between the virtual and real physical spaces together with the respective objects.

From a chronological point of view, the relationship of physical objects and processes with their virtual (digital) aspects is one in development and is manifested by the level, the measure of integration. According to [18], several stages can be characterized:

1. The physical space predominates, everything depends on it.
2. The virtual space appears, is growing and improving.
3. Physical and virtual space interact.
4. Physical and virtual space interact more and more and tend to converge.

The transition from stage two to stage three was determined by the implementation of the concept of computer integrated manufacturing (CIM), CNC digitization of machine tools, computer-aided development CAD/CAE/CAM of products. The industry is currently going through the third stage through the emerging technologies of the Internet of Things (IoT) and Big Data analysis, which facilitate the interaction between physical and virtual spaces. The launch of the fourth stage is determined by the development of the Digital Twins (DT) concept, which uses intensive interaction in both directions (phisical - digital, digital - phisical) thanks to informational and cyber-physical systems.

One of the first clear definitions of a digital twin was given by NASA: “A Digital twin is an integrated multi-physics, multi-scale, probabilistic simulation of a vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its flying twin” [19]. A digital twin is a virtual representation of machines, products, processes, any system in the real world based not only on the spatial image, but also on the data provided over time by information systems, the Internet of Things (IoT), sensors, etc. The digital twin enables better understanding, analysis, performance improvement, proper maintenance of industrial systems and products.

Digital twins can be created and completed in two different situations. In the first situation, the physical object is designed with modern computer-aided tools, so that from the very beginning it also exists in the digital version with a level of detail determined by the computer program used. The models are continuously updated through changes based on the data generated directly by the physical objects [20, 21]. The second situation refers

to the situation when the virtual version is not available, also because the existing physical object was designed with classical tools. Thus, the completion of the digital twin is produced in augmented mode, starting from image recognition or captured characteristics of the physical object.

Depending on the nature and direction of the data flow between physical and virtual systems, the notions of digital model, digital shadow and digital twin can be defined [19].

The digital model of an existing physical object or process does not provide for the automatic exchange of data with the physical object, so that the digital model once created is not able to reflect the changes over time of the physical object (Figure 3a).

In the case of the digital shadow, there are flows data generated by the physical object both automatically and manually directed to the digital object so that it is updated with new information from the real world (Figure 3b).

In digital twins, data flows are automatic and bidirected. A change to the physical object is automatically reflected in the digital object and vice versa. Thus, the digital object allows the formation of the data necessary to control the functioning of the physical object appropriate to the external and internal situation. The foundation of the digital twin is the connection of the physical and the digital (Figure 3c).

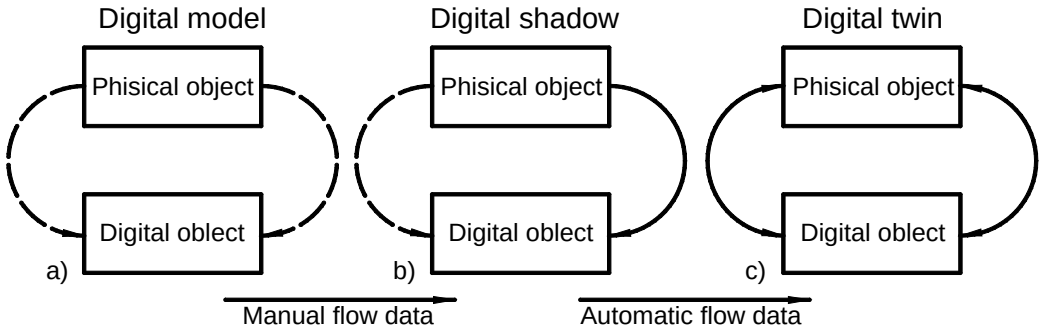

Figure 3. Digital model (a), digital shadow (b) and digital twin (c) [22].

The simulation differs from the digital twin in that it characterizes the future states of the physical object based on the initial set of data and hypotheses [23]. The digital twin interconnects physical and digital object data and forms the datasets for simulation. Thus, simulation in the context of digital twins becomes a practically continuous process [19, 20].

In the context of digital twins, the approaches related to the methods of analysis, design and simulation of objects and processes as subsystems are changing. It is a natural reflection, most modern engineering objects and processes being extremely complex, so it is logical to have multiple teams of experts from different fields working in parallel. The subsystems operate on the basis of the different physical laws and at different dimensional scales (macro, meso, micro, nano) and, consequently, they can hardly be integrated into a common model [24].

The main function of a digital twin is the combination of approaches based on modeling and on collected data to obtain a virtual forecasting tool that can evolve over time. In this sense, the digital twin offers the possibility to solve technical problems in engineering applications. The reduction of uncertainties related to the application of knowledge in decision-making is achieved by using the data objectively recorded by the physical twin, through real or representative laboratory tests. It is important that the data recorded and delivered are characteristic of twinned structures. In the organizational aspect, the digital twin uses a hierarchical format, a fact that facilitates the integration of objects and processes of different physical origins and on several

dimensional scales. The goal of overcoming organizational obstacles is also pursued by improving connectivity through logical interfaces for the various calculation and simulation models [24]. Figure 4 shows model V of product development on the stages of the life cycle in the traditional version (a) and in the version that also includes the digital twin cycle (b).

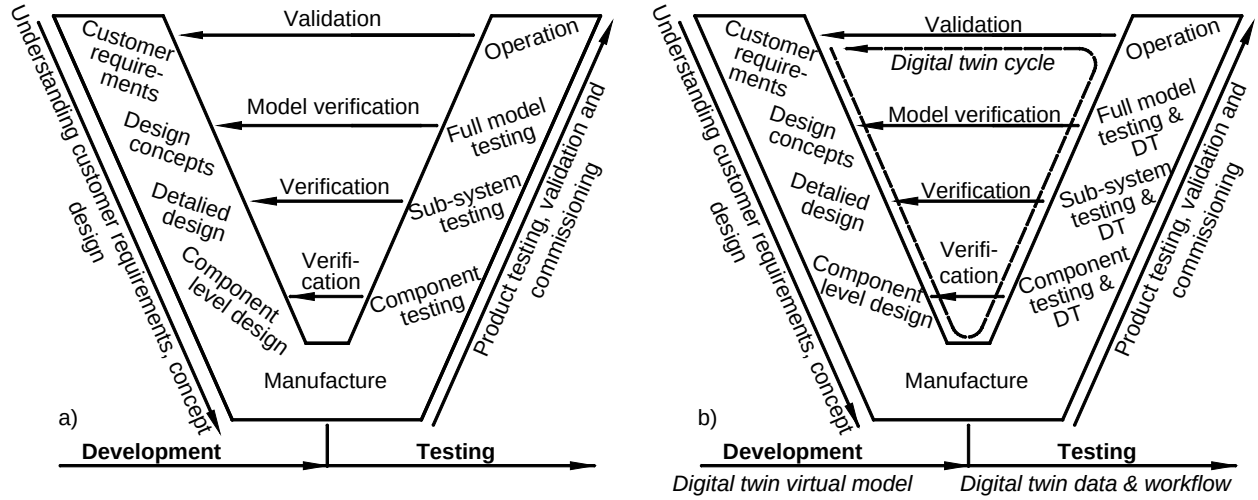

Figure 4. V model representing the life cycle of the product: a) traditional model, b) model that also includes the cycle of the digital twin (DT) [24].

Simulations and the creation of digital twins refer to objects and processes, products and technologies to the same extent. The digital twin includes information - factors (representing influences or potential influences) adequately and objectively determined by the work team and accumulated during the stages of the life cycle.

Based on the same factors, models of objects/processes or their components are created for simulations. Defining the factors is a complex process, which is based on knowledge and experience.The complexity of selecting and defining factors is related to the fact that factors can be obvious and implicit, systematic and random, can manifest independently or in connection with other factors, can manifest synergistically, etc.The origin of the factors is very diverse and refers to the transformation couples: needs – requirements, requirements – functions (use values), functions – physical-technical principles, physical-technical principles – constructive variants (structures), constructive variants – technical parameters, technical parameters – processes, processes – technology, technology – manufacturing, manufacturing – testing, testing – exploitation, Figure 5.

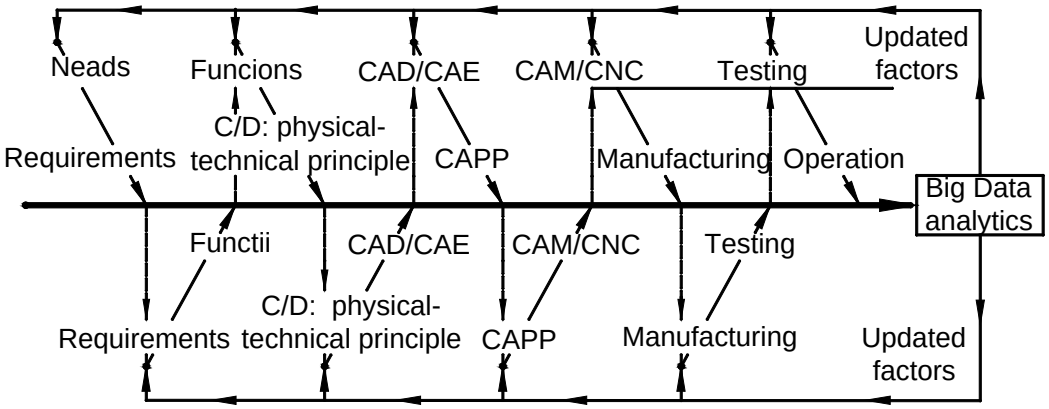

Figure 5. Updating the technology factors of the product's life cycle stages.

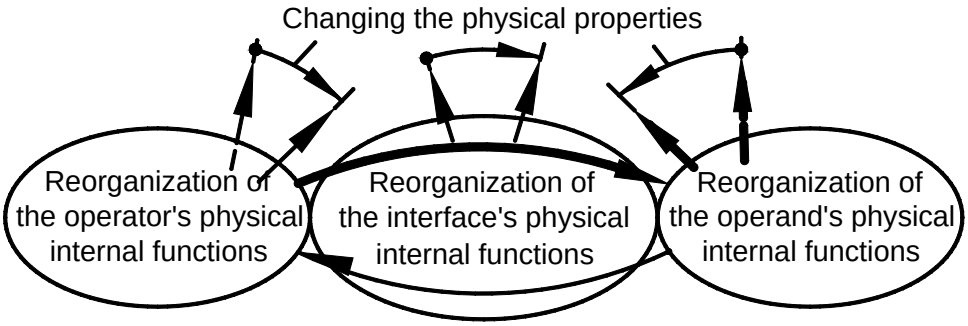

Figure 6. Changing the physical properties of the operator, operand and interface by reorganizing their internal functions.

Representation through transformations allows the process character of the life cycle to be highlighted. Unlike the V model represented in figure 4, the transformation by couples approach can be represented by the technological function model (Figure 6) [25].

The result of the technological function are the changes in the properties of the operand, the operator and the functional interface. These changes are produced by reorganizing the internal functioning of the mentioned objects with external functional effects of each of them.

The interaction between operator and operand occurs through functional interfaces. The number and character of the interfaces depends on the fizico-technical conditions considered and on the physical-technical phenomena resulting from the interaction.

Figures 7 and 8 show, respectively, digital shadow and digital twin models based on the technological function model and the interpretation of these notions according to [22].

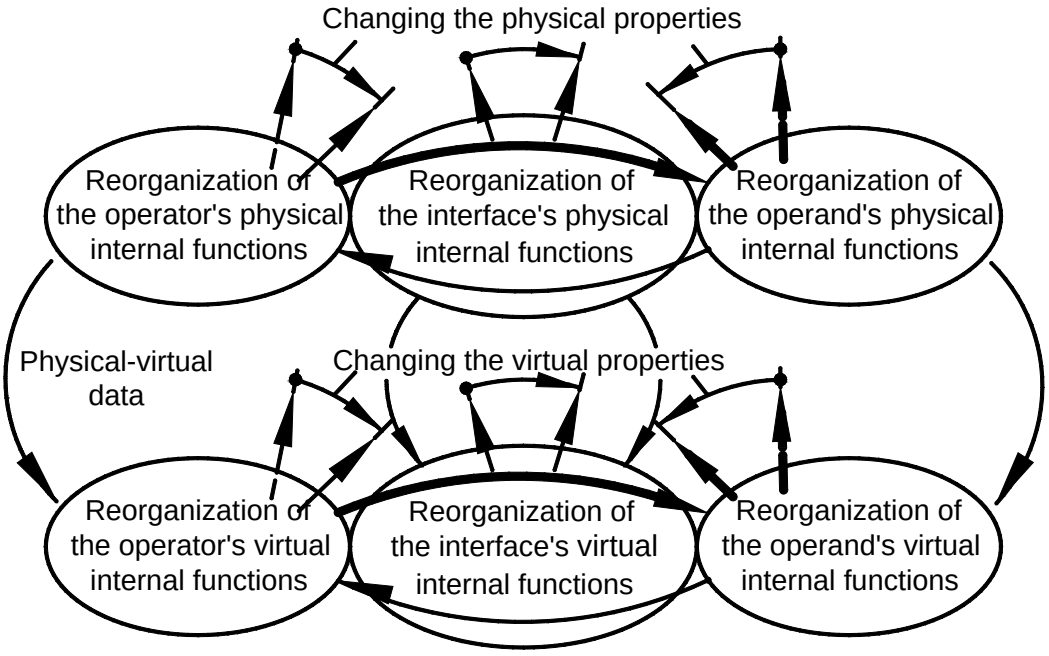

Figure 7. The update virtual properties by reorganizing operator, operand and interface virtual internal functions (digital shadow).

As an example, the information that must be processed to create a digital twin of the product can be described:

- the set of user needs that must be satisfied by the product;
- the set of requirements for the product;

- the set of (external) functions of the product;
- the physical-technical principle of operation, of the principle scheme;
- the CAD model of the product assembly with the specification:

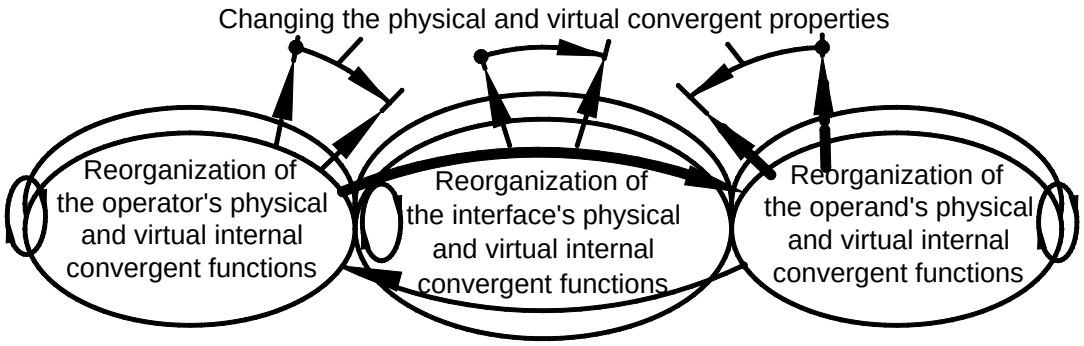

Figure 8. Synchronizing the change of physical and virtual properties by reorganizing the physical and virtual internal functions of the operator, operand and interface (digital twin).

- ✓ informational origins of complex components (subassemblies);
- ✓ adjustments, dimensions and tolerances, gauge dimensions, etc.;
- ✓ the materials of the parts and the heat treatments with references to the respected standards regarding the representative properties important for the operation in conditions of resistance, rigidity, thermal regimes, wear, etc.;
- ✓ the regime parameters of the sliding and restoring torques;

- CAE models and simulation results:
  - ✓ product functionality;
  - ✓ the operation of the product and/or its assemblies;
  - ✓ resistance, rigidity, reliability of components, etc.;
- CAPP models and the description of the elaborated process parameters;
- the characteristics of machine tools, of other machines involved in technological processes (model, functional parameters, precision, etc.);
- the characteristic of cutting tools, of other tools involved in technological processes (model, code, functional parameters, precision, etc.);
- CAM/CNC models and description of machining parameters;
- the results of the technical control of the parts, testing, trials with the concretization of fits, etc.;
- the parameters of the packaging, storage and transportation conditions;
- parameters in real time of functionality and operating recorded by sensors and information systems, etc.;
- regime and maintenance parameters;
- liquidation regime and parameters.

From the point of view of maturity, the digital twin's technology is an emerging one, it is one that has significance in many aspects of engineering, it can offer new solutions to the current and potential problems faced by the engineering of complex objects and processes.

5. Conclusions

- Currently, technological transfer has become largely oriented towards the digitization of products and processes and depends on: the level of basic technical and human digital capabilities, the level of modernization and integration of technological resources, the

level of modernization of digital infrastructure, the level of accessibility to new digitized technologies, etc.

- The pillar technologies of the Industry 4.0 concept are diversified by function, but form a systemic whole, so that for strategic success it is necessary to implement them also in a systemic regime.
- Technological development resources are limited for small and medium-sized companies, so it is necessary to set certain priorities. Since several companies in the Republic of Moldova are foreign-owned and mixed, they operate with modern technologies, and for the markets of developed countries, technologies for simulation and creation of digital twins and design of products with high physical-cyber content can be prioritized.
- Technologies for simulating and creating digital twins are sufficiently complex, so the path to digital twins can be traversed, gradually passing through intermediate variants of digital model and digital shadow.
- Models for creating digital twins refer exclusively to the product life cycle, with the emphasis being placed on the finalities of the life cycle stages.
- The paper proposes a digital twin model based on the technological function, in which the modification of the properties is manifested by the restructuring of the internal functions of the operator, the operand and the interface. The central place in this model belongs to the interface, which reflects the multitude of physical-technical processes at different scales of macro, meso, micro analysis characteristic of objects and processes in machine building.

Conflicts of interest: The authors declare no conflict of interest.

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ANNEALING EFFECT ON UV DETECTION PROPERTIES OF ZnO:Al STRUCTURES

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Abstract. The aim of this study was to develop low-powered, highly selective UV sensor to continuously monitor personalized UV exposure as well as to study annealing effect on UV detection properties of the sensors. ZnO:Al structures were obtained by chemical growth method followed by thermal annealing at 625 °C for 2 h. The studied samples exhibit maximal UV response of 620/488 at 25 °C/50 °C to 370 nm UV radiation before/after annealing, respectively. Thermal annealing of sensor (250 °C for 1 h) led to improvement in fall time from 3860 seconds to 262 seconds at 25 °C and highest responsivity (~48 mA/W) came out for 370 nm wavelength at 75 °C operating temperatures. Consequently, excellent selectivity for 370 nm UV illumination can be ascribed as due to thermal annealing effect which increases the crystallinity, grain size, and roughness of the sensing film. The PL measurements reveals the suppression of structural defects, increase in intensity after annealing and enhanced UV response due to presence of Al content in films. Overall, these structures showed magnificent UV properties, before and especially after additional thermal annealing. UV sensing mechanism of such nanomaterial-based sensor were explained with physio-chemical processes take place on the surface of these structures. The obtained results on annealed ZnO:Al films-based devices is superior to reported performances of other nanostructures, proving new results for UV sensing applications at different operating temperatures in various fields.

Keywords: *semiconductor oxide, heterostructure, sensor, selectivity, efficiency, sensing mechanism.*

Rezumat. Scopul acestui studiu a fost de a dezvolta un senzor UV de putere redusă, foarte selectiv, pentru a monitoriza continuu expunerea personalizată la UV, precum și pentru a studia efectul de recoacere asupra proprietăților de detectare UV a senzorilor. Structurile ZnO:Al au fost obținute prin metoda de creștere chimică urmată de recoacere termică la 625 °C timp de 2 ore. Probele studiate prezintă un răspuns UV maxim de 620/488 la 25 °C/50 °C până la 370 nm radiații UV înainte/după recoacere, respectiv. Recoacere termică a senzorului (250 °C timp de 1 oră) a condus la îmbunătățirea timpului de cădere de la 3860 de secunde la 262 de secunde la 25 °C și cea mai mare capacitate de răspuns (~48 mA/W) a rezultat pentru o lungime de undă de 370 nm la temperaturi de funcționare de 75 °C. În consecință, selectivitatea excelentă pentru iluminarea UV de 370 nm poate fi atribuită ca fiind datorată efectului de recoacere termică care crește cristalinitatea, dimensiunea granulelor și rugozitatea filmului de detectare. Măsurătorile PL relevă suprimarea defectelor structurale, creșterea intensității după recoacere și răspunsul UV îmbunătățit datorită prezenței conținutului de Al în pelicule. În general, aceste structuri au arătat proprietăți UV magnifice, înainte și mai ales după recoacere termică suplimentară. Mecanismul de detectare UV al unui astfel de senzor pe bază de nanomateriale a fost explicat cu procesele fizico-chimice care au loc pe suprafața acestor structuri. Rezultatele obținute pe dispozitivele pe bază de filme recoapte ZnO:Al sunt superioare performanțelor raportate ale altor nanostructuri, dovedind rezultate noi pentru aplicațiile de detectare UV la diferite temperaturi de funcționare în diferite domenii.

Cuvinte cheie: *oxid semiconductor, heterostructură, senzor, selectivitate, eficiență, mecanism de detectare.*

1. Introduction

Radiation in ultraviolet spectrum plays a crucial role in our daily life. We can observe its distinct outcomes, even if we do not visualize it with naked eye. We find enormous applications of distinct ultraviolet (UV) radiations in domestic and industrial fields, but we also get affected by its over exposure. Ultraviolet (UV) light can adversely affect human body especially eyes, and special lenses are used with a wavelength filter in the ultraviolet range 400 – 450 nm to minimize UV influence on it [1]. Kraemer et al. demonstrated effect of UV light small group of people with basal cell nevus syndrome and other skin disorders which may cause skin cancer [2]. Ultraviolet light source provides efficient light used in several areas such as: creating integrated circuits [3]; medicine [4–7]; food industry [8,9]; agriculture [10]; cosmetics [11,12]; personalized sensors [13], etc. In integrated circuits, UV light cures light–sensitive materials, e.g., photoresist as a substrate [3]. In the field of dental medicine, ultraviolet is used to cure biocompatible polymers for the restoration of fractured teeth [4]. Additionally, UV light is used on the skin to reduce inflammation and trigger biological processes in dermatology in so-called phototherapy [7]. Another application of ultraviolet light in medicine is for disinfection, e.g., during the SARS-CoV-2 period rooms were systematically illuminated with the aim of decontamination [5]. In food industry, UV light is used instead of thermal treatment of liquids, so the pasteurization process is no longer necessary [8]. Agriculture is still influenced by UV irradiations significantly with positive effects. Recent studies have shown that short-term exposure of plants to ultraviolet radiation positively influences the exposed plant by increasing the levels of bioactive substances [10].

Devices with UV light-emitting diodes (LEDs) are used in cosmetics to cure nail polish. These devices are easily accessible in domestic conditions, but at the same time raise possible complications to patients in dermatology and ophthalmology [11]. Different substances used in cosmetics are also being studied to filter ultraviolet rays coming from the sun [12]. The purpose of UV sensors is to continuously monitor exposure time of human body to ultraviolet rays [13]. Of course, the ultraviolet rays that are emitted by the sun are essential for the human body to synthesize vitamin D which itself is necessary for muscle health, but excessive exposure to these rays can lead to various aggravations. The main adverse consequences are cutaneous malignant melanoma, squamous cell carcinoma of the skin or basal cell carcinoma of the skin [14]. In addition, the skin loses its elasticity, ages faster and can develop solar keratoses. There are also serious effects of UV radiation on the eyes such as cataracts, which can cause various complications such as complete loss of vision as well as pterygium. So, the applications of UV radiation require rigorous control, especially in areas related to human health.

Wide-bandgap metal oxide semiconductors have been shown to be high-performance UV photodetectors with promising photo responsivities compared to commercial devices. ZnO is preferred among these materials for use in UV photodetector because it possesses a wide direct band gap (~3.37 eV) corresponding to the energy of an ultraviolet photon, native *n*-type conductivity, and high exciton binding energy (60 meV) at room temperature, which are properties unique and attractive for UV photodetection. Besides these, ZnO can be obtained by various technologies, and especially attractive structured nanomaterials, which open new promising applications. Altering the band gap energy of the sensing structure by doping of is necessary to adjust the sensing range and improve the selectivity for a given UV illumination spectrum [15,16]. Aluminum is frequently used to achieve better optical and electrical properties of ZnO by replacing Zn^{2+} ions with Al^{3+}. Azizah et al. demonstrated [17] that apposite Al doping may increase the energy of the band gap and illustrated that the Al doping enhances photo to dark current ratio. The increase in the ZnO band gap may be due to the occupation of the lowest levels in the conduction band by the electrons of the Al impurity atoms which causes a direct transition with higher energy. The optical band gap values were those obtained by room temperature photoluminescence spectra in ZnO and ZnO:Al [18]. An illustrated example shows doping of ZnO with 3% Al allows the expansion of band gap from 3.37 eV to 3.9 eV and the increase of the electron density of electrons by about 5 times (up to $4.5 \cdot 10^{20}$ cm^{-3}). Hence, Al-doping improves photosensitivity of ZnO. Most of the studies based on ZnO:Al photodetection illustrates sensing at relatively high bias voltages, e.g. at about 5 V. Therefore, it is the high interest to investigate effect of annealing on the UV detection performances of aluminum-doped ZnO films.

Our current study showed an excellent ZnO:Al structures exhibiting decrease in photo current fall rate at low bias voltage of 1 V with excellent rejection ratio of >20 times to other interfering wavelengths i.e., 385 nm and 394 nm after thermal annealing. Ultraviolet spectrum with diverse applications shows bittersweet character, so it is necessary to develop personalized sensors for determining the exposure of different surfaces to UV inclusively and determining the wavelength that is applied at the time of the actual exposure. In this work structural properties of ZnO:Al depositions are studied with its UV sensory properties at three UV wavelengths in different operating conditions and annealing effect.

2. Materials and Methods

The ZnO:Al structures have been obtained by the chemical method, which is easy to achieve and effective from the point of view of costs [19], followed by thermal annealing at 625°C for 2 hours [20], techniques presented in detail previously [19,21,22]. Thermal annealing improves the crystal quality of thin films synthesized in chemical solutions [21–23] by densifying them compared to those obtained at room temperature.

The structural, morphological, photoluminescence and micro-Raman studies were analyzed and discussed in detail. For measurement of XRD, graphite monochromatized $CuK_{\alpha 1}$ radiation with wavelength as λ =1.5405 Å using Siefert 3000TT unit at 40 mA and 40 kV.

UV Installation

Schematic setup of the measuring installation shown in Figure 1. The measuring installation consists of the following discrete modules: LEDs of different wavelengths are placed on a round aluminum printed circuit board in the UV diapason. This printed circuit board is rotated by a stepper motor, ensuring that the emitting LED is placed exactly on the sample under study.

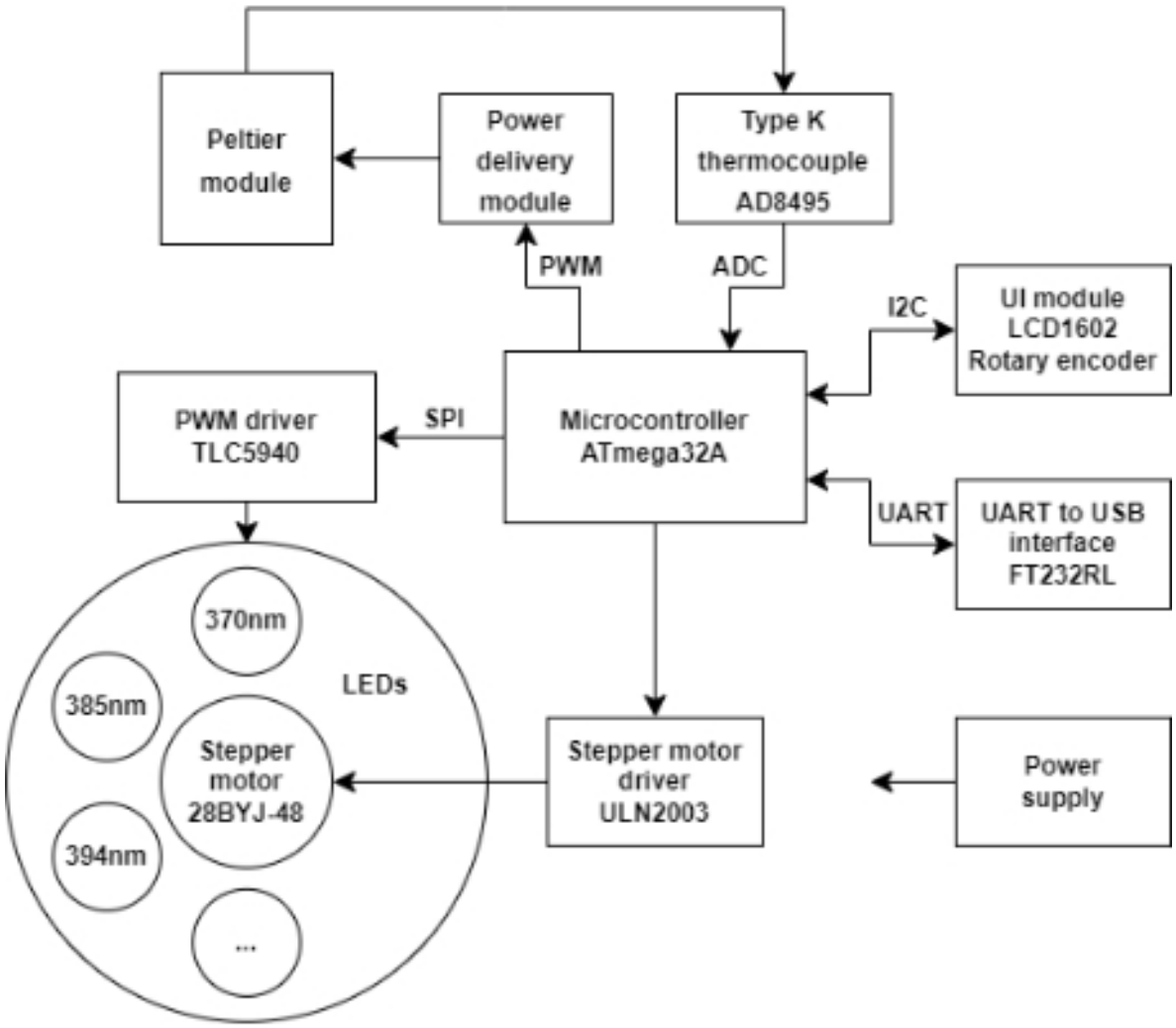


Figure 1. Schematic setup for testing the fabricated UV sensors at different regimes.

The light intensity of the LEDs is set via a PWM controller TLC5940, capable of setting the exact level of illumination the LED will provide. From minimum to maximum

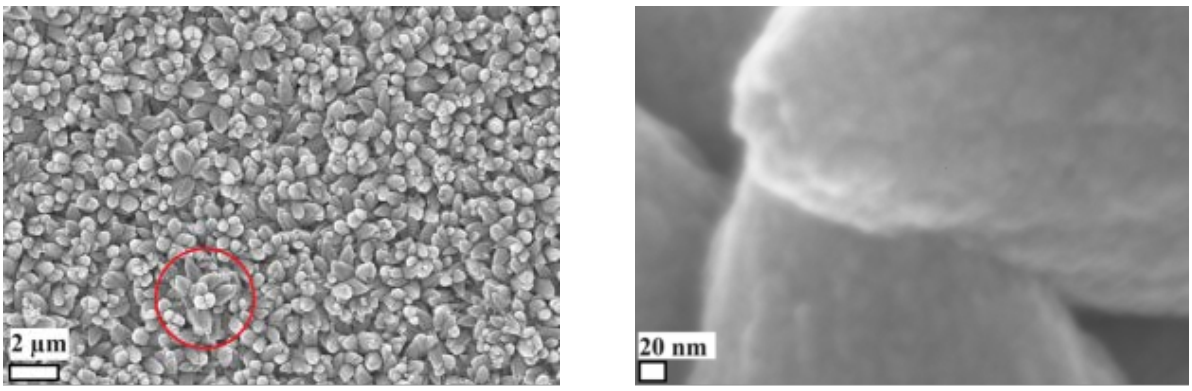
value, we can have about 4000 different intensities. The working frequency of the PWM is about 2 kHz. The maximum current limit applied to the LED was 100 mA.

To study the response of the sample at different temperatures in the installation, a Peltier element is used. This element makes it possible to set the sample temperature in the range -10 to +100 °C. The Peltier element is controlled by a module which consists of a power MOSFET transistor and a relay with a double group of contacts. The transistor is driven with a PWM signal generated from the result of the proportional-integral-differential (PID) controller. The feedback signal for the PID, is acquired via a K-type thermocouple. The signal from this thermocouple is amplified via the AD8495 and applied to an ADC input of the microcontroller. Depending on the polarity of the voltage applied to the Peltier element, it will heat or cool the sample. The polarity change is done by using a relay with 2 groups of contacts.

Setting the wavelength, the applied light intensity and the temperature at which the measurement is made can be done in two ways. The first mode is the manual mode, the selection of the required parameters is done by means of the rotary encoder and the menu will be displayed on an LCD screen. The second mode involves connecting the measuring system to the computer via the USB port, this allows greater flexibility in generating UV radiation pulses. The measurement of the sample is taken in electrical current. Sample data being acquired via Keithley Model 2450 source meter. The entire configuration is supervised by special software. All baseline measurements were performed at a bias voltage of 1 V. In such a way it is possible to compare results.

3. Results and Discussion

The investigation of surface morphology and composition of ZnO:Al structures were analyzed by using SEM/EDX set-up. The SEM image of structural surface and morphology of ZnO:Al layer is as shown in Figure 2. It was observed uniform deposition on the glass substrate film of interconnected columnar grains, Figure 2. In some regions, interconnected columnar nanostructures form a flower-like (marked in red circle on Figure 2a morphology, most probably due to Al-doping and impurity segregation. Interconnected columnar grains have an advantage for sensing applications [24] due to an increased surface as adsorption sites. At higher magnification (Figure 2b) it was observed that columnar grain has rough surface which is another advantage for sensing applications, by increasing surface to volume ratio [24] and columns are interpenetrated and creates a huge number of potential barriers in between.



a) b)

Figure 2. SEM images of ZnO:Al structures at different scales: a) 2 µm; b) 20 nm showing columnar and interpenetrated nano- and micro-crystals.

For XRD measurements, $CuK_{\alpha 1}$ radiation source of Siefert 3000TT diffractometer was used with reflection geometry using PIXcel detector in 2θ range of 20° to 60° values were recorded. The XRD characterization carried out to study the crystallinity of ZnO:Al film used for developing sensors. It shows XRD pattern of film with multiple ZnO diffractions as $(10\bar{1}0)$, (0002), $(10\bar{1}1)$, $(10\bar{1}2)$, $(10\bar{2}0)$ at respective angles as shown in Figure 3. The major ZnO diffraction peak is (0002), at 34.3° with highest intensity showing a hexagonal structure and preferential growth along *c*-axis as already observed in our previous studies [24]. These reflexes can be attributed to PDF 036-1451 for ZnO and no alumina reflexes can be observed is ascribed as due to amorphous nature or much lower quantity of Al-related material vs ZnO, ZnO:Al film after thermal annealing at 625°C for 2 h and this can be attributed to PDF 00–004-0787.

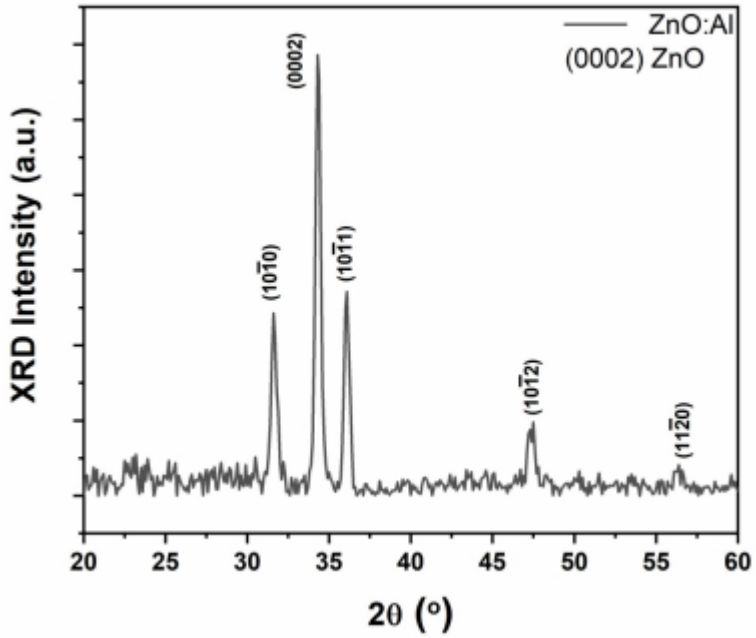


Figure 3. XRD pattern of studied ZnO:Al structure.

MicroRaman scattering investigations on developed samples were done at 22°C with a WITec LabRam Alpha 300 system in a backscattering configuration. The 532 nm laser was used for off-resonance excitation with less than 5 mW power at the specimen. Using optical objective lens placed on optical microscope, focusing of light was controlled on the sample surface. The CCD detector was used to collect photons and detect quickly the whole spectra.

To study the structural quality of these ZnO:Al layers on the substrate, detailed microRaman spectroscopy measurements at various locations in the specimen have been done. The absorption band edge of ZnO:Al layer was studied.

In figure 4(a) is presented micro-Raman spectra of ZnO:Al structure at room temperature, observing E_2(high)-E_2(low), A_1(TO) and E_2(high) modes at 330, 375 and 435 cm^{-1}, corresponding to wurtzite ZnO [24].

From Figure 4(b) we observed that E_2(high) mode is distributed uniformly, which indicates a high crystal quality of the film [24], as observed in SEM results. The clusters formed are characterized by sizes (Figure 2) and roughness (Figure 4b) corresponding to ZnO:Al made at low synthesis temperatures and not thermally treated one.

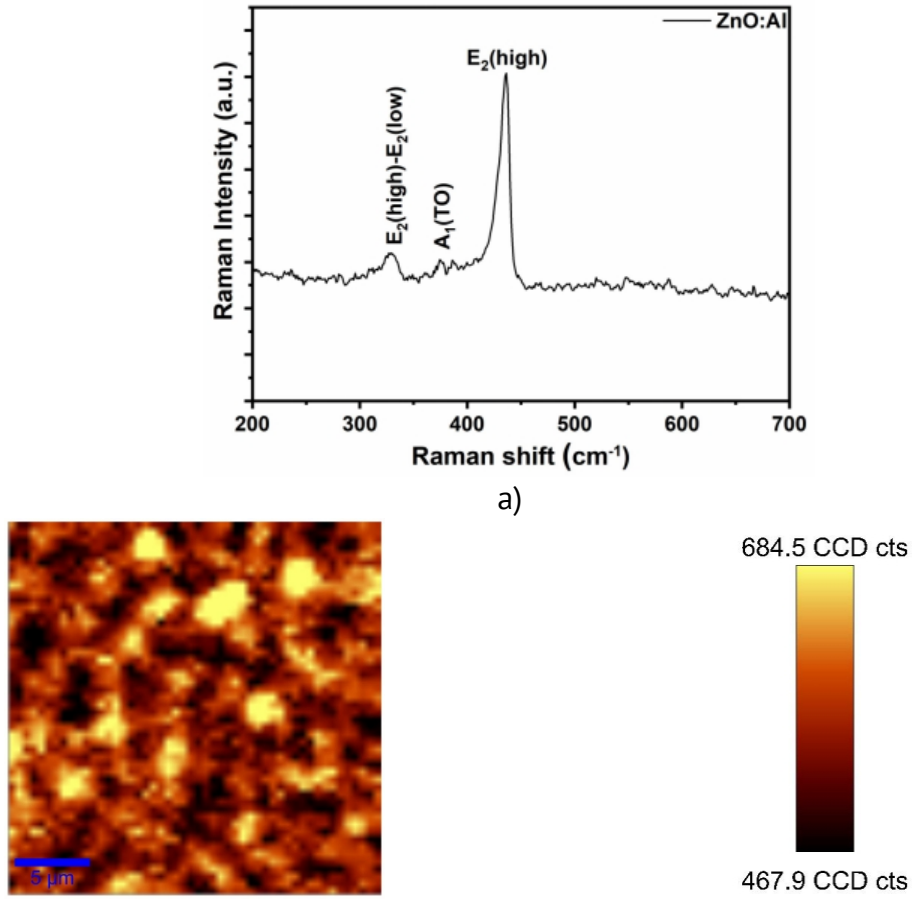


Figure 4. Micro-Raman spectra of ZnO:Al structure (a). Micro-Raman mapping of ZnO:Al structure (b).

When we talk about UV detectors, an important parameter is the dependence of their performance on working temperature. ZnO:Al structures presented in this research article exhibited a significant response at 370 nm wavelength at an operating temperature of 25 °C (Figure 5). The response of ZnO:Al to UV light can be explained by electronic and optical properties as shown in Figure 5. Al content in ZnO can deteriorates structural defects and enhances UV sensitivity [18] after thermal annealing.

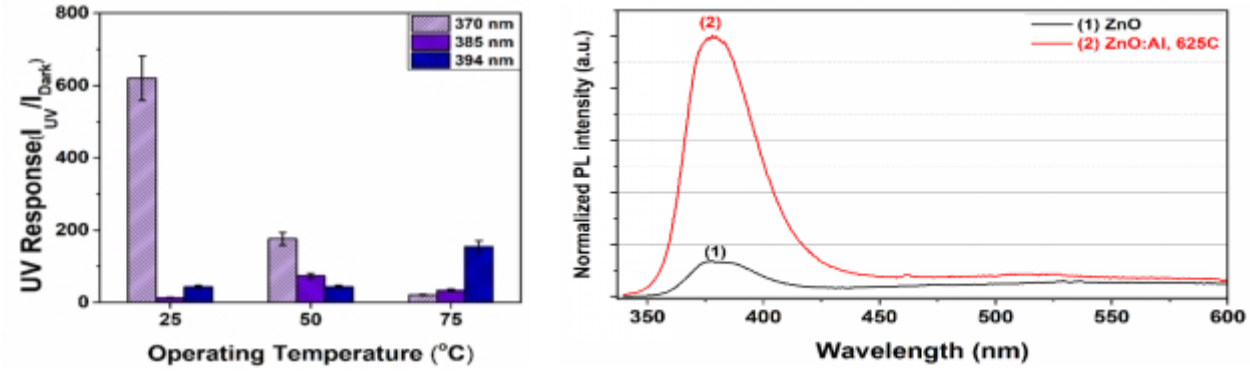


Figure 5. UV Response of ZnO:Al structures at different wavelengths versus operating temperature (a). Normalized photoluminescence of ZnO and annealed ZnO:Al at 625 °C (b).

Upon exposure to UV light, ZnO:Al structure shows a significant increase in photoconductivity attributed to enhancement in number of free charge carriers as a result of generation of electron–hole pairs by absorption of photons from UV light illumination (370 nm, 4.1 μW).

In absence of additional thermal annealing for sensor, its UV response for λ=370 nm monotonically decreases by increase in operating temperature from 25 °C to 75 °C (Figure 5a). This is due to cumulative effect resulting from bandgap changes, increase in crystal lattice scattering, increase in dark current with temperature caused by carrier thermogeneration, and favor of oxygen diffusion neutralizes some of the oxygen vacancies of ZnO caused by Al presence in ZnO matrix as reported previously [25]. Due to thermal annealing and Al diffusion onto the sensing surface of developed sensor, there is decrease in visible spectra luminescence related to lattice defects and increase in UV luminescence at about 370 nm (Figure 5b) could be considered as due to effective activation of Al diffusion after initial thermal annealing at 625°C for 2 h, confirmed in previous reports too [26]. Consequently, this contributes to excellent sensitivity of 370 nm over other higher wavelengths.

An increase in excitation wavelength (from 370 to 394 nm) leads to decrease in value of the UV response due to several competing factors (decreasing energy of absorbed photons, increasing absorption coefficient of material) [27].

Figure 5a shows UV response of such ZnO:Al structure-based sensor before thermal annealing (at 250 °C for 1 h) measured at operating temperature of 25 °C. At this temperature, we observed response of 620 at 370 nm wavelength, and response of 43 for the wavelengths 394 nm as shown in Table 1 for comparison. With increase in operating temperature of these nanostructures, a decrease in response to 370 nm wavelength is observed. Error bars in Figure 5a shows standard deviation in represented UV response value within 10% error.

Table 1

UV response before thermal annealing for ZnO:Al structures at different UV wavelengths. Operating temperatures of T= 25 °C, 50 °C, and 75 °C.

Temperature	UV Response, λ=370 nm	UV Response, λ=385 nm	UV Response, λ= 394 nm
25 °C	~620	~13	~43
50 °C	~176	~73.5	~43.4
75 °C	~22	~34	~155

Thus, before thermal annealing of sensor (at 250 °C for 1 h) measured at low operating temperature of 25 °C, wavelength of 370 nm is considered as optimal ascribed as due to ZnO:Al energy bandgap (~3.35 eV) correspondence to optimal wavelength as shown in Eq. (1).

$$EQE, \eta = \frac{hcR}{\lambda q} \quad (1)$$

Response and fall times of the ZnO:Al structures for the wavelength 370 nm at operating temperature of 25 °C is as shown in Figure 6. Response/fall time is defined as time taken to achieve 90%/10% of its maximum response value, respectively. We note that response time is approximately 39 seconds and the fall time 4109 seconds for 25 °C operating temperature.

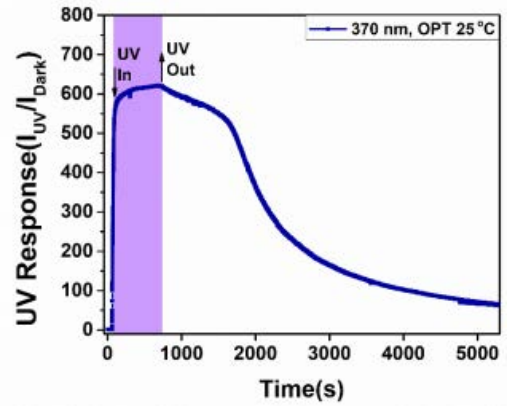


Figure 6. Dynamic UV response of ZnO:Al structure-based sensor measured under UV radiation (370 nm) before thermal annealing of the sample. The operating temperature is 25 °C.

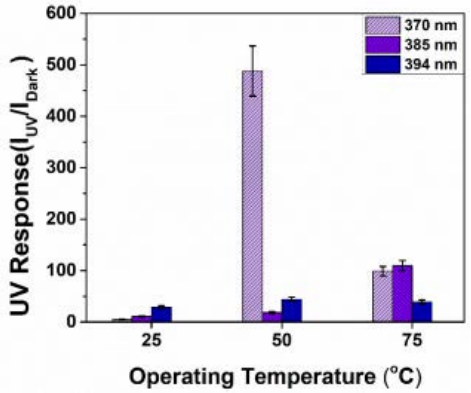


Figure 7. UV response of ZnO:Al structure-based sensor vs operating temperature. The sensor structure was thermally annealed at T_{ann} = 250 °C for 1 hour in air and measured at temperatures of 25, 50 and 75 °C, respectively. UV excitation was 370, 385 or 394 nm, respectively.

Figure 7 shows the UV response of ZnO:Al structure-based sensor after thermal annealing (at 250 °C for 1 h) and measured at operating temperatures of 25 °C, 50 °C, and 75 °C. Error bars in Figure 7 has standard deviation in represented UV response value with 10% error.

Data processing tells us (Table 2) that at operating temperature of 25 °C, we observed response of ~4.7, ~10.8 and ~28.7 for the wavelengths 370 nm, 385 nm and 394 nm, respectively. It was observed that at working temperature of 50 °C for 370 nm UV illumination device exhibits response of ~488 which is about 102 times higher than at other tested wavelengths, where relatively lower response values of approximately ~18.3 and ~43.8, respectively. After thermal annealing of sensor structure, it was observed that UV response at 75 °C comes out to be ~99, ~109 and ~39 for 370 nm, 385 nm, and 394 nm wavelengths, respectively. Thus, after thermal annealing maximum response at operating temperature of 50 °C for optimal wavelength 370 nm was observed as ~488.

Table 2

UV response for ZnO:Al -based sensor after thermal annealing investigated at different UV wavelengths and measurement temperatures (25 °C, 50 °C and 75 °C).

Temperature	UV Response, λ=370 nm	UV Response, λ=385 nm	UV Response, λ=394 nm
25 °C	~4.7	~10.8	~28.7
50 °C	~488	~18.3	~43.8
75 °C	~99	~109.4	~39

Figure 8 shows the dynamic response of ZnO:Al -based sensor after thermal annealing (at regime 250 °C for 1 h). The thermal annealing of entire sensor exhibits excellent improvement in its fall rate and UV response for 370 nm illumination as compared to sample before thermal annealing and measured at operating temperature of 50 °C. UV response increased from 176 to about 488 and the fall time reduces to 449 seconds as shown in Figures 5, 7 and 10, respectively.

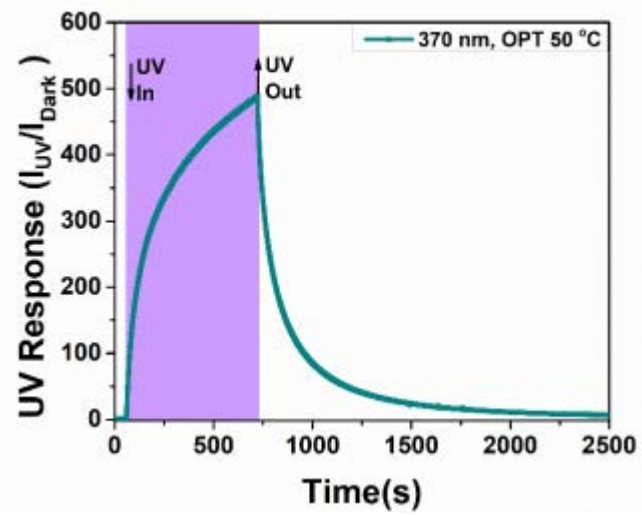


Figure 8. UV Dynamic response of ZnO:Al sensor after thermal annealing and investigated at radiation wavelength of 370 nm and operating temperature of 50 °C.

The dynamic response of the ZnO:Al sensor after thermal annealing and investigated for the different applied bias voltages as show in Figure 9. It was observed for applied bias voltage of 0.1 V (Figure 9 (curve 1)) rise time and fall time of approximately 325 seconds and 306 seconds, respectively. At an applied bias voltage of 0.5 V (Figure 9 (curve 2)), we obtained rise time of 449 seconds and fall time of about 585 seconds for this sample. At an applied bias voltage of 1 V, we measured response time of 449 seconds and fall time of 448 seconds, observed in Figure 9 (curve 3). When applying bias voltage of 5 V observed in Figure 9 (curve 4), the response time is 485 seconds, and the fall time is 738 seconds. From Figure 9, it can be concluded that at an applied bias voltage of 0.5 V and 1 V response time is almost identical, while fall time differs by about 140 seconds. Applying bias voltage of 5 V increases the fall time significantly by a ratio of about 1.6 times, but a response time remains same.

UV response analysis of semiconductor material is a complex process. It depends upon lot of operating parameters that can be controlled to optimize desired UV response at appropriate conditions. Under influence of applied bias voltage and UV illumination, electron-hole pairs generation and recombination may occur. For ZnO:Al -based sensor structures transient properties of UV detection influenced by applied bias voltage as given by E=V/L, where E, V, and L represents applied electric field due to bias voltage, potential difference between electrodes, and distance between electrodes, respectively.

By increase in applied bias voltage, electric field across sensing electrodes increases. Hence stronger charge carrier separation ability, large amount of photo generated charge carriers and fall time increases at higher bias voltage [15].

$$I_{ph} = \frac{q.\Phi.n.\tau_{carrier}}{\tau_{transit}} \tag{2}$$

where:

$$\tau_{transit} = \frac{l^2}{\mu V} \tag{3}$$

where: I_{ph}, $\tau_{transit}$, Φ, n, $\tau_{carrier}$, μ, l, and V represents UV current, transit time across sensor active region, number of photons incident on sensing surface per second, absorption

quantum efficiency, carrier life time, mobility of charge carriers, length of electrode, and bias voltage, respectively.

By increasing applied voltage UV current also increases from Eq. (2) and (3) [28]. Hence, UV response increases by increase in applied bias voltage.

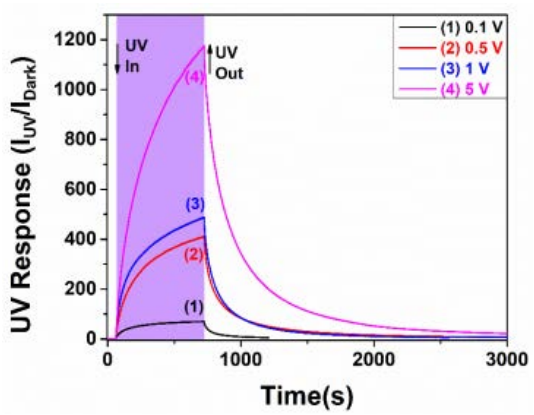


Figure 9. UV Dynamic response of ZnO:Al-based sensor after thermal annealing and investigated at radiation wavelength of 370 nm and operating temperature of 50 °C. Applied bias voltages were (1) 0.1 V; (2) 0.5 V; (3) 1 V; and (4) 5 V, respectively.

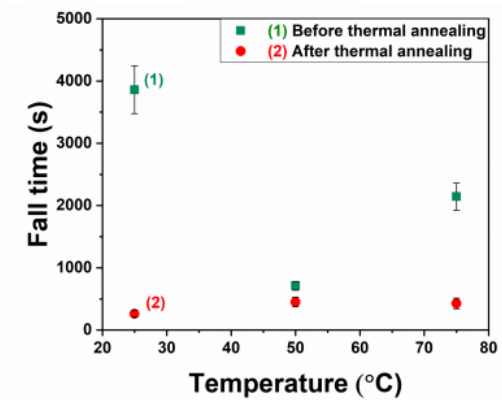


Figure 10. Effect of thermal annealing of sensor structure on its fall time versus operating temperature under UV irradiation.

Effect of thermal annealing on fall time for ZnO:Al -based sensor after thermal annealing can be seen in Figure 10. The thermal annealing of sensor structure at a temperature of 250 °C for 1 h improves the UV fall and enhances the fall rate for UV illumination at optimal conditions i.e. 370 nm as shown in Figure 10. This may be due to faster evacuation/extraction of electrical charge carries. The error bars in Figure 10 has standard deviation in represented fall time value with 10% error. Before thermal annealing, UV decay rate after UV inactivation was slow especially at operating temperature of 25 °C, but after thermal annealing decay rate becomes fast enough irrespective of operating temperature [29]. After annealing, elimination of deep trap states enhances the surface quality and increases the recovery rate [30].

Thermal effect on sensor structure effectively contributes to conductivity of material and enhances current contribution to the sensing surface. By increasing operating temperature, more electrons reach to the conduction band which leads to increase in carrier concentration. Consequently, it enhances conductivity and current on the sensing surface. This can be understood well with the help of following two relations [31]:

$$\sigma = ne\mu_e \tag{4}$$

$$n = \sqrt{N_D N_C}.\left(\frac{2\pi m_e kT}{h^2}\right)^{\frac{3}{2}}.\exp\left(-\left(\frac{E_C - E_D}{2kT}\right)\right) \tag{5}$$

where: σ represents electrical conductivity at given temperature, n is intrinsic carrier concentration, μ_e is electron mobility, N_D represents density of donor states, N_C represents density of states in conduction band, m_e represents effective mass of electron, E_C and E_D represents bottom edge energy of conduction band and donor level energy, respectively.

Figure 11 can be ascribed by Eq. (4) and (5). As it shows, carrier concentration increases by increase in temperature which leads to the increase in electrical conductivity (or current). Since, oxide semiconductor has negative temperature coefficient of resistance. Thus, current increases by increase in operating temperature.

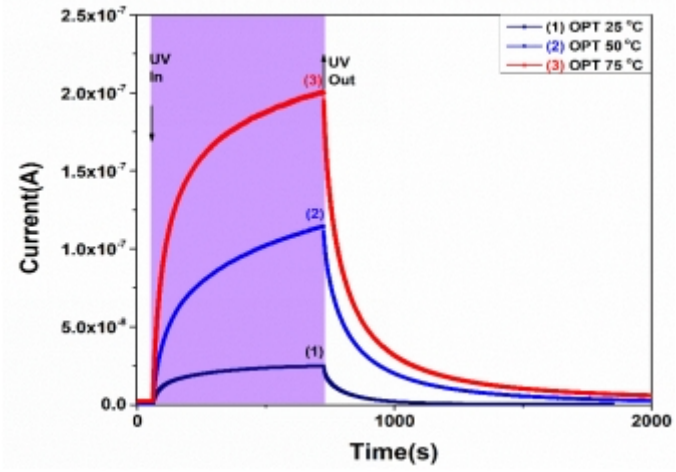


Figure 11. Effect of operating temperature on electrical current as a function of time (dynamic responses) for ZnO:Al -based sensor after thermal annealing and investigated at different operating temperatures.

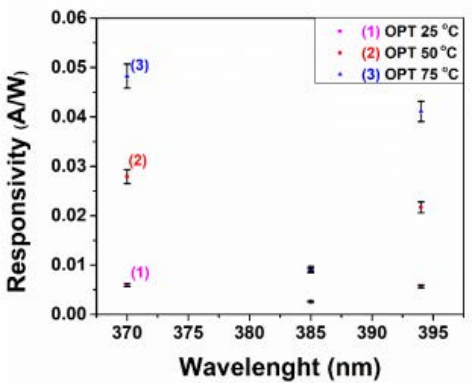


Figure 12. Responsivity of ZnO:Al -based sensor after thermal annealing and investigated at different operating temperature *vs* UV wavelengths of applied radiation.

Maximum responsivity at 370 nm is ascribed as due to energy bandgap correspondence of ZnO:Al to ~370 nm wavelength. Due to presence of Al in ZnO microparticles, high temperature annealing (625 °C, 2 h) provides more activation energy influences Al^{3+} ions and allows diffusion of Al^{3+} into the sample through interstitial mechanism which leads to excellent sensitivity [32]. In Figure 12, 385 nm and 394 nm peaks are accounted for acceptor bound exciton and free electron to acceptor emission [33], respectively.

After thermal treatment, UV responsivity comes out to be maximum for optimal wavelength 370 nm at operating temperature of 75 °C as shown in Figure 12. Error bars in Figure 12 has standard deviation in represented responsivity value with 10% error.

$$\sigma = \sigma_0 e^{\frac{-E_a}{k_B T}} \tag{6}$$

where: σ, σ_o, E_a, k_B, and T represents conductivity at given temperature, conductivity at absolute temperature, activation energy, Boltzmann constant, and operating temperature, respectively.

By increasing temperature, conductivity increases as shown in Eq. (6) [34]. Thus, it contributes to carrier concentration and hence responsivity enhances as shown in Eq. (7):

$$Responsivity = \frac{(I_{UV} - I_{dark})(for\ given\ \lambda)}{P(for\ given\ \lambda)}, \left(\frac{A}{W}\right) \tag{7}$$

where: I_{UV}, and I_{dark} represents UV current and dark current respectively (A), P represents optical power for each wavelength (Watt).

External quantum efficiency calculated for all three wavelengths as shown in Eq. (8) and it comes out to be maximum for 370 nm at operating temperature of 75 °C as 0.16 which is eight to ten times higher than at other tested UV-wavelength, i.e. 385 nm.

$$EQE, \eta = \frac{hcR}{\lambda q} \tag{8}$$

where: η is external quantum efficiency, λ is illuminated wavelength, q is carrier charge, h is Planck's constant, c is speed of light, and R is responsivity.

Table 3 shows calculated of Responsivity R and external quantum efficiency at three different UV wavelengths used in this work and as shown below.

Table 3

Responsivity and external quantum efficiency of ZnO:Al structure-based sensor after thermal annealing measured at three different UV wavelengths. Operating temperatures were (25 °C, 50 °C and 75 °C).

Wavelength, nm	Responsivity, 25 °C	Responsivity, 50 °C	Responsivity, 75 °C	EQE, 25°C	EQE, 50°C	EQE, 75°C
370	0.006	0.027	0.048	0.020	0.090	0.160
385	0.002	0.008	0.009	0.006	0.025	0.028
400	0.005	0.021	0.041	0.015	0.065	0.127

A sensing mechanism proposed for investigated sensors

By increase in temperature, dark current increases exponentially as described by Arrhenius Eq. (9) [16]

$$I_d = A.I_{d_o}.exp\left(-\frac{E_a}{k_B T}\right) \tag{9}$$

where: A is proportionality constant, k_B is Boltzmann constant, E_a is activation energy, I_{d0} is preexponential factor and T is the operating temperature.

According to the results from Figure 5a, optimal wavelength comes out to be 370 nm which exhibits maximum response as 620 among all other UV-A wavelengths ascribed as due to the energy band gap correspondence to 370 nm wavelength for ZnO:Al at operating temperature of 25 °C. From PL spectra, 370 nm peak can be attributed to the localized bound exciton emission at longer wavelength caused by the Al diffusion on ZnO sensing surface [35]. Due to the presence of Al, this peak blue shifted to 370 nm. SEM image in Figure 2b shows rough surface due to presence of Al in ZnO leads to absorption of 370 nm UV irradiation and enhancement in sensitivity towards UV range near to its band gap energy correspondence [36,37].

Due to UV illumination at 370 nm wavelength ensure electron-hole pairs generated after photon absorption as shown in Eq. (10).

$$h\nu \rightarrow e^- + h^+, \tag{10}$$

where h, ν, e^-, and h^+, are Planck's constant, frequency of illuminated radiation, photogenerated electron and hole, respectively.

UV absorption not only contributes to electron-hole pairs generation but also leads to chemisorption of oxygen molecule and their surface kinetics reactions with generated electron-hole pair as shown in Eq. (11) and (12):

$$O_{2(gas)} + e^- \rightarrow O_{2\ (ads.)}^- \quad (11)$$

$$O_{2(ads.)}^- + h^+ \rightarrow O_{2(desorp.)}, \quad (12)$$

where: $O_{2(gas)}^-$, $O_{2(ads.)}^-$ and $O_{2(desorp.)}$ represents oxygen gas molecule, adsorbed oxygen ion and desorbed oxygen molecule, respectively.

The surface charge carriers' kinetics vary by UV illumination. In an ambient environment, oxygen gaseous molecules react with free electrons and get adsorbed on sensing surface as shown in Eq. (11) which leads to decrease in electrical conductivity of ZnO networks. This is due to *n*-type character of ZnO networks in which electrons are the majority charge carriers which contributes to the conduction process. Under UV illumination ($h\nu > E_g$), a photogenerated electron-hole pair occurs as shown in Equation 10 where photogenerated electrons contribute to the enhancement in electrical conductivity and photogenerated holes also reacts with adsorbed oxygen ions as shown in Eq. (12). Finally, this process leads to the desorption of oxygen from the sensor surface.

Diffusion of Al in ZnO (which anyway has many defects (oxygen vacancies)) additionally forms electrons that reduce the amount of O_2 by reducing it to ion forms, especially to the form of superoxide O_2^-. Increasing the concentration of such oxygen radicals increases the catalytic reactions of the ZnO:Al surface, additionally amplified by UV irradiation. This overall leads to an increase in the sensitivity of the sensor to UV spectra. This can be confirmed through SEM and PL spectra results as shown in Figure 2b, 4a, and 5b, respectively.

Figure 13 shows general UV sensing mechanism proposed for such ZnO:Al structures. Eq. (11) and (12) elucidates this UV sensing mechanism in equation form. As Eq. (11) demonstrates reaction of free electrons with oxygen gas present in atmosphere and transition from initial stage represented in Figure 13a to stage represented in Figure 13b. Next, Eq. (12) demonstrates adsorbed oxygen reaction with photogenerated holes which leads to the oxygen desorption and transition from stage represented in Figure 13c to stage represented in Figure 13d after UV illumination on the sensing surface of the sensor.

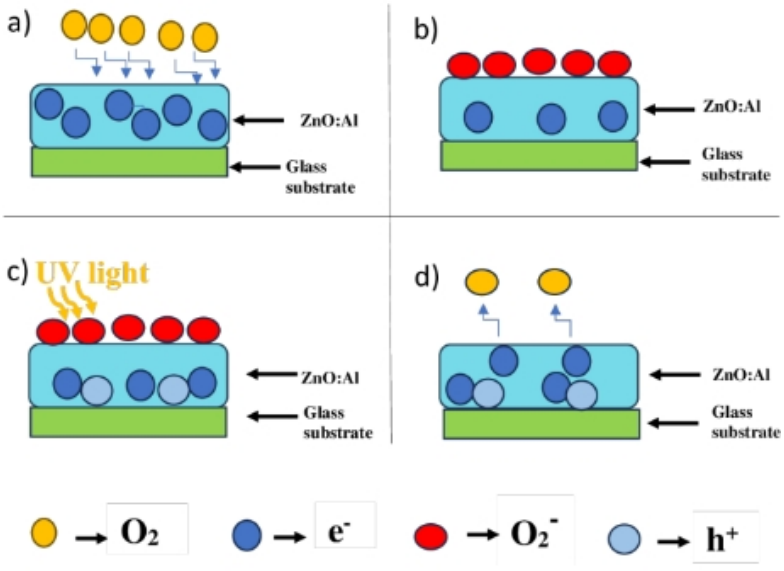


Figure 13. Schematic representation of UV sensing mechanism proposed in four stages: a) Initial stage without oxygen adsorption; b) oxygen adsorption; c) UV excitation; d) oxygen desorption.

5. Conclusions

Although UV radiation is a form of non-ionizing radiation, its presence in nature (10% of solar UV radiation penetrates the atmosphere and reaches the Earth's surface), in multiple industrial processes, in specific applications like (tanning bed, mercury vapor lighting in stadiums, school gyms, some halogen, fluorescent and incandescent lights, some types of lasers, etc.) is a serious reason for ensuring effective monitoring of exposure to UV radiation. It is important to remember that in 2009 the WHO declared UV radiation as completely carcinogenic, as it is both a mutagen and non-specific damaging agent and it plays a role in both initiating and promoting tumors.

Due to the need to control the presence and level of ionizing radiation, multiple researches are initiated, including the development of new sensors based on semiconductor structures such as ZnO doped with Al. The results obtained and presented in the research of the ZnO:Al structure as UV radiation sensors can be concluded by the following.

ZnO:Al structures not subjected to thermal treatment are promising as sensors for UV detection at room temperature. Their thermal treatment leads to an increase in their working temperature. Thus, depending on the operating conditions, the same structures by simple thermal annealing change the optimal operating temperature, thus ensuring a selectivity of the sensor.

The PL spectra denote the effect of Al doping and thermal annealing on enhancement of UV intensity and removing of visible ranged defects.

Increasing the applied bias voltage provides an improvement in the UV response current for the optimal wavelength of 370 nm.

Thermal annealing leads to a remarkable improvement in fall response time irrespective of operating temperature for thermally annealed sensors. An increase in temperature causes an increase in current which can be ascribed as due to the thermal contribution to current and hence, conductivity of ZnO:Al structure. Overall, maximal responsivity is demonstrated by UV irradiation with optimal wavelength of 370 nm which is about ten times higher as compared to another interfering wavelength of 385 nm at 75 °C. This study exhibits excellent UV response at room temperature and at higher temperatures even with low optical illumination of 4.1 μW and relatively low applied bias voltage of 1 V which elucidates its excellence for range of photodetection applications. A mechanism is also presented that explains the sensitivity of the ZnO:Al structure to UV radiation in different operating conditions.

The monitoring of UV rays is one of the necessary criteria to limit its adverse impact on human health at the level of the natural rays emitted by the sun as well as the artificial ones emitted by various domestic and industrial devices used in working conditions.

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EMBEDDED DEVICES AND METHODS FOR DEVELOPMENT OF SPECIAL NON-CONTACT APPLICATIONS

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Abstract. There are applications which require particular approaches for each of the used parts. The non-contact strain sensors based on microwires with positive magnetostriction requires specific technological processes starting from casting until development of the corresponding non-contact sensor device. The developed contactless sensors can be embedded into various industry critical parts which require continuous monitoring and maintenance. Hence, specific embedded devices and specific framework should be developed to provide industry reliable solution. The paper describes the technological process of casting microwires, methods of improvement casting process and stress annealing methodology used to obtain appropriate non-contact sensible elements based on microwires. Also, the paper describes the framework of using these elements in non-contact monitoring applications of the condition of specific engineering objects/structures.

Keywords: *contactless sensing, microwire, strain sensor, collimation group/device, embedded system, edge computing device.*

Rezumat. Există aplicații care necesită abordări speciale pentru fiecare dintre părțile utilizate. Senzorii de deformare fără contact pe bază de microfir cu magnetostricție pozitivă necesită procese tehnologice specifice începând de la turnare până la dezvoltarea unui dispozitiv senzoric fără contact. Senzorii fără contact dezvoltați pot fi încorporați în diferite părți critice din industrie care necesită monitorizare și mentenanță continuă. Prin urmare, ar trebui dezvoltate dispozitive încorporate specifice și o arhitectura specifică pentru a oferi soluții de încredere pentru industrie. Lucrarea descrie procesul tehnologic de turnare a microfirelor, metode de îmbunătățire a procesului de turnare și metodologia de recoacere la stres utilizată pentru obținerea de elemente sensibile fără contact corespunzătoare pe bază de microfire. De asemenea, lucrarea descrie cadrul de utilizare a acestor elemente în aplicații de monitorizare fără contact a stării unor obiecte specifice.

Cuvinte cheie: *senzori fără contact, microfir, senzor de deformare, grup/dispozitiv de colimare, sistem încorporat, dispozitiv de calcul la margine.*

1. Introduction

It is well known that composite structures are prone to external mechanical loads and to variations in environment conditions, both of which could lead to major degradation of their mechanical conditions. Therefore, using Structural Health Monitoring (SHM) becomes paramount in a number of fields like civil engineering, aerospace industry or energy. SHM generally refers to any type of damage detection procedure. Generally speaking, SHM is the automation of the condition assessment process of an engineered system [1, 2].

To systematically monitor the condition of structures, SHM relies on a mix of technologies and methods. These are aimed at sensing, analyzing collected data and elaborating computational models able to predict the occurrence of damages. In this context, a critical challenge is in designing the sensing solution, which is a difficult task. The field implementation of sensing solutions is still in its infancy, attributable to different economic and technical issues.

There are applications in which sensible element should be integrated into monitored environment to have a better picture over the processes inside. An example of such non-contact sensor application is strain gauge based on microwires (SGM). Such sensible elements can be used in applications with contactless measurements for composite materials [3, 4]. These kinds of sensors require meticulous casting process along with other technological processing to develop a suitable sensor for special applications. Last but not least, applications can have an extraordinary impact on industry only considering the constrains of the sensors and modern Machine Learning (ML) [2, 5] approach along with latest edge computing technology [6, 7], its high scale integration into microcontrollers or cloud computing. Note that ML for SHM has become popular due to technological advances in sensors [8, 9], high-speed Internet and cloud computing.

It can be concluded that distributed embedded sensing systems as well as custom platforms need to be explored/developed in order to provide industry-specific robust and cost-effectively solutions.

2. Strain sensors based on microwires

In order to identify the manufacturing technology of strain sensors based on microwires, a technological and testing program of microwires was established. The objectives of the program were defined as:

- Researching the ordering processes of the amorphous structure under the action of temperature and the stretching processes of microwires from alloys with positive and negative magnetostriction.
- Identification of alloy composition, processing methods, with the aim of obtaining microwires with a high dependence of coercive force on external mechanical stresses.
- Research of the processed microwires, especially the characteristic of the magnetic properties depending on the applied stretching stresses.

A lot of microwires were selected for research. They can be grouped by material properties as follows:

- With positive magnetostriction: $Fe_xB_ySi_z$, $Co_wFe_xB_ySi_z$, $Co_vFe_wCr_xB_ySi_z$.
- With negative or close to 0 magnetostriction: $Co_vFe_aCr_xB_ySi_z$, $Co_aFe_bB_ySi_z$.

The size of selected microwire was 20±3; 30±3; 45±5 μm with a glass coat of 3±1; 6±1. For the selected wires the following research and measurements were targeted:

- Measurement of the actual diameters of the core and the thickness of the glass coat.
- Measurement of magnetic characteristics when adding stretching loads (pulse forms and parameters of the hysteresis loop), as well as in the temperature range of 20 - 50 ° C (preferably 20 - 100 ° C).

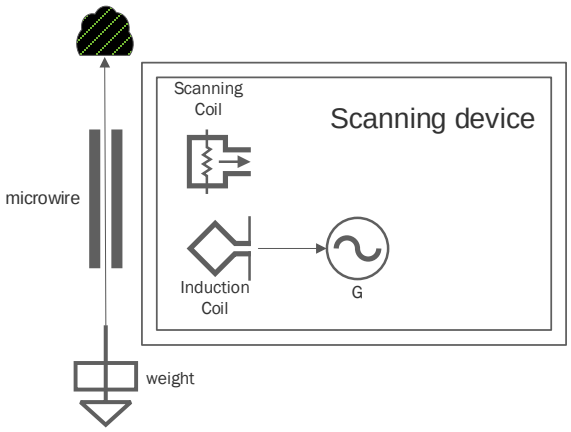

Figure 1. Stand for checking magnetic characteristics response.

Initially a study was performed to find the more appropriate materials with given characteristics which were able to provide a response in the magnetic characteristics when a stretching force was applied. A simple stand (see Figure 1) was designed to perform this preliminary research.

According to the preliminary research for many materials a change in coercive force (*Hc*) was identified, Figure 2. For the measured samples it was identified that microwires reached the strain hardening region, were change in coercive force was relatively low for a wide range of the applied tensile stress. Moreover, many samples were prone to reach the necking region or even broke, which would make the microwires unsuitable to be used as strain sensors.

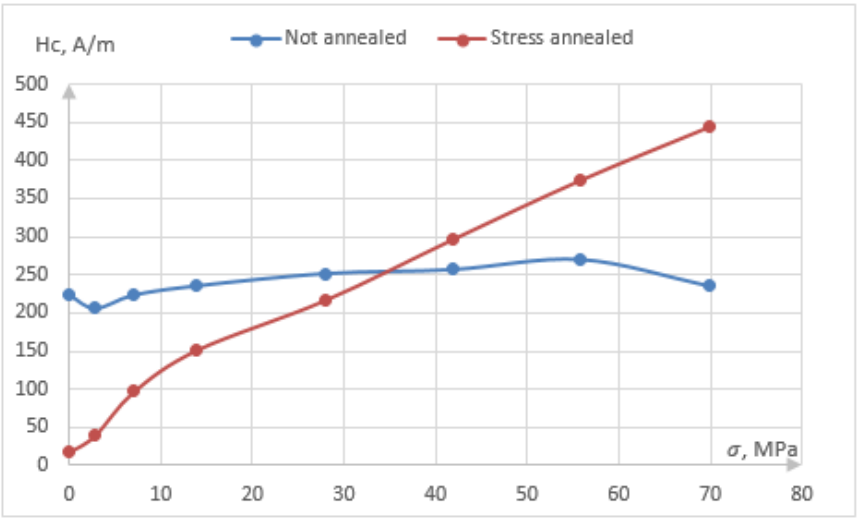

Figure 2. Dependence of the coercive force (Hc) on the applied tensile stress (σ).

Even if some of the studied materials may show low sensibility to stretching, this can be improved by performing annealing or stress-annealing. Stress-annealing of microwires is

performed by exposing an amorphous microwire based on ferromagnetic alloy to a higher temperature in stretched state. The exposing temperature is less than crystallization temperature, thus the alloy core keeps the amorphous state, but the closest atomic layer is restructured along the applied force. At this temperature the glass coat almost doesn't change its shape. After stress-annealing, under normal conditions, the tension in the core of microwire is decreased or even has constringent characteristic [10].

Thus, it is very important to perform a research on thermomechanical processing in order to reach higher sensibility for strain sensors. According to preliminary results of research at Microfir Tehnologii Industriale, Ltd, the stress-annealed microwires had a wider range sensibility and depending on material and stress-annealing technology, a wider range of sensibility can be obtained. Thus, a research process for microwires stress-annealing has been developed, to identify the appropriate technological process for various applications. The processing of microwires included research considering various temperature value, stretching forces and speed through processing furnace.

The ratio of the tensile stress for microwires can be calculated according to the expression:

$$\sigma_m = \frac{kP}{kS_m + S_{gl}} \tag{1}$$

where: *k* is *Em/Egl*: Young's modulus for the used metal (alloy) and glass, *P* is the applied stretching force, S_{gl} and S_m are the cross sectional areas for glass and used metal. According to the expression (1) a set of weights were used to apply a tensile stress in range of up to 70 MPa.

Considering the impact of stress-annealing and (1), the expression for calculating of coercive force would be:

$$Hc = f(\sigma_m, V_a, T_a) = K_0 + K_1\sigma_m + K_2V_a + K_3T_a, \tag{2}$$

where: V_a and T_a are annealing speed and temperature. K_0, K_1 and K_3 are coefficients which can be identified for a given annealing process and microwire to create a sensor with required characteristics.

The sensible element can be used in applications with contactless measurements for composite materials. By integrating microwire into monitored environment, access to it can be difficult, or depending on the embedding process of sensible element, its response can vary. For this situation a special adjustment procedure should be considered, but this wouldn't be suitable for mass production cases.

The strain measuring characteristics can be significantly improved by using a reference microwire which is strain tolerant, but has an appropriate coercive force to the sensible microwires (Figure 3). Thus, the research process considered also the microwires which have a magnetostriction close to 0. Reference microwire can provide a reference signal which makes the measurement device to be more tolerant on displacement with sensible element. Research process also identified the more suitable reference microwires for sensible microwires with given characteristics. Considering the fact that microwires are based on amorphous materials it is important to perform research on its elastic characteristics. The purpose of this research was to identify the impact of multiple stretching cycles on the microwire characteristics, especially on microwires developed for strain gauge.

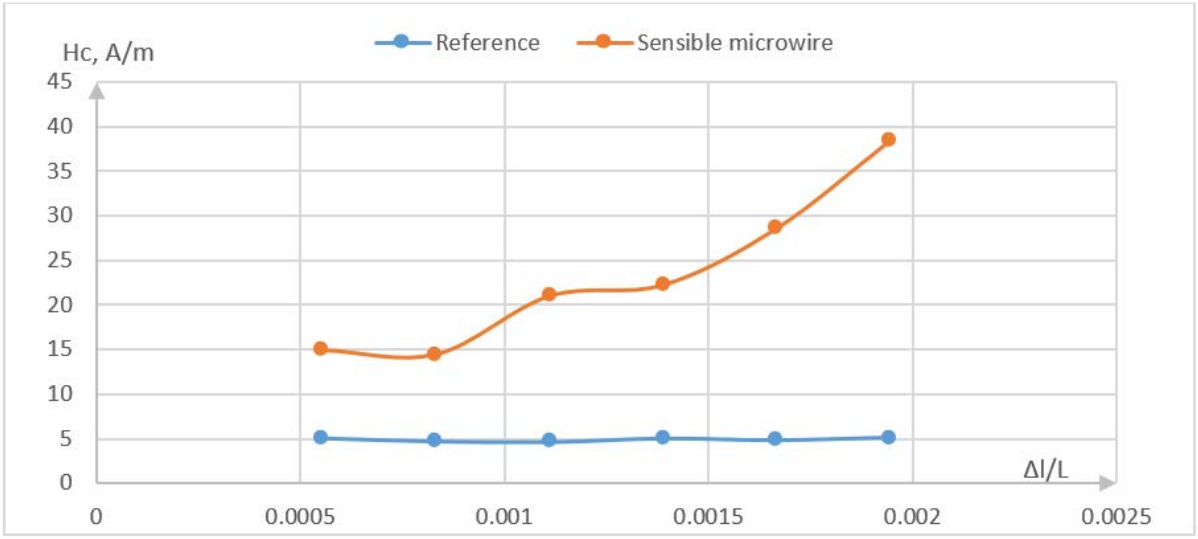

Figure 3. Change in coercive force (Hc) under elastic strain (Δl/L).

For research of microwire magnetic and elastic strain characteristics a system was developed, Figure 4. The system includes the following main parts:

1) plain BH meter designed for embedded sensible microwires;
2) stretching mechanism;
3) support for microwires installation.

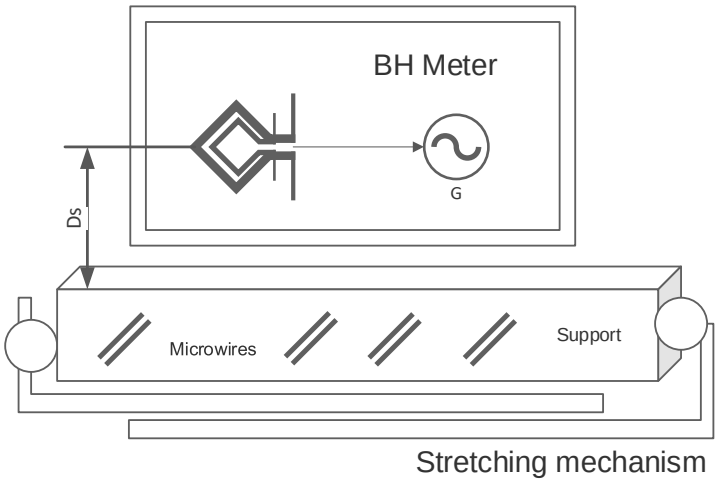

Figure 4. Magnetic and elastic strain charateristics measurements.

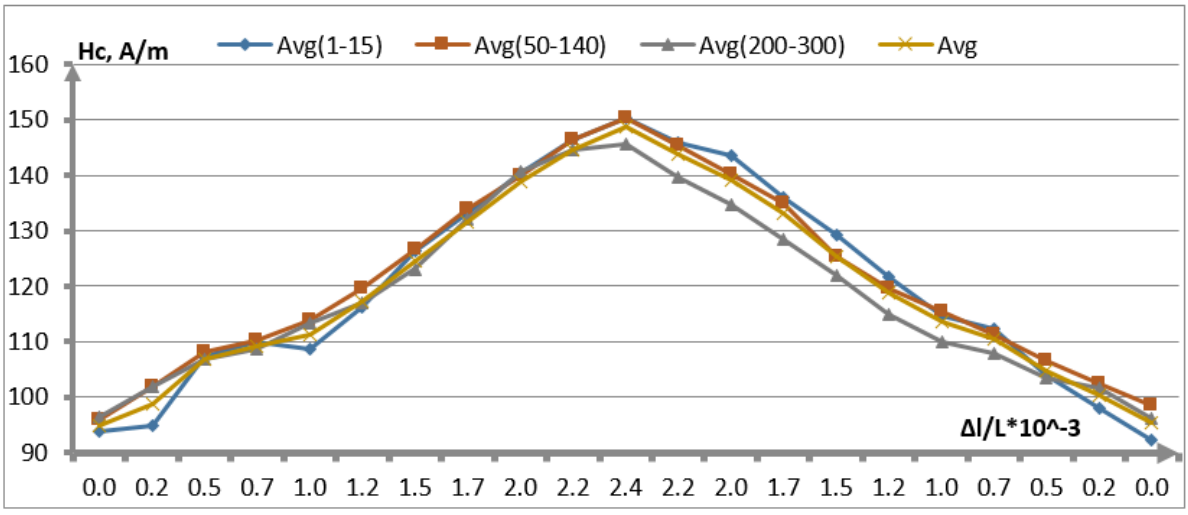

Figure 5. Change in coercive force (Hc) as a function of cyclic elastic strain (Δl/L).

Many microwires could be installed on the measurements support, which made possible to measure characteristics of all the installed microwires in one measurement cycle. According to the performed measurements, the investigated microwires had shown stable sensibility in the range of testing stretch. In large, the magnetic response didn't change over many stretching cycles (Figure 5), thus it can be considered that for elastic stretches the sensibility is stable.

3. Monitoring and control of microwire production

One of the main aspects of the study was radiographic analysis of microwires. Separate research was performed by measuring M-H curves for a few selected samples, which had performance difference in spite they were from the same production lot. It was decided to observe the magnetic, geometrical and chemical properties by employing Scanning Electron Microscopy (SEM). Also, the wires were observed including Energy Dispersive X-Ray Spectroscopy and Electron Back Scatter Diffraction.

Microscopic observations using SEM suggested several facts which can lead to difference in performance for microwire based sensors. For few samples could be inferred that glass coating in respect to its metallic core brings to a better sensor noise. For other samples it was noticed that circularity of the microwires, as well as their uniformity in thickness of the glass coating are very important aspects of stress distribution and homogeneity applied to the metallic core [11].

The outcome of radiographic analysis was that microwire production process based on Taylor-Ulitovskiy method should focus more on parameters tuning and control. The resulting optimization of microwire production should lead to control of microwire geometrical shape and its stability along process. Usage of a standard MR meter during casting is not enough considering that it has accuracy of 5 to 10% with quite narrow limits. Moreover, the MR meter cannot be used for a wide range of microwire diameters. A significant improvement into casting process can bring an intelligent embedded device based on concept of microwire diameter measurements based on optical transparency [12]. This new method can be used for measurement of microwire parameters during casting process [13]. The method can provide such useful information for casting process as core diameter and its glass coat thickness. Thus, it is a way to provide information about process, especially when microwire diameter, circularity and glass coat thickens are critical for its production as strain sensors. Only providing this information in time, during casting can improve the final quality of microwires.

Considering that casting process according to Taylor-Ulitovskiy method represents a harsh environment for measurements of microwire geometrical parameters, a special approach, using edge computing should be designed.

The proposed concept of microwire diameter measurement is based on microwire transparencies for different wavelength. This method is precise enough for large diameters of microwire core and thick glass coat ($>20\mu m$). For such microwire the casting process is accurate enough to keep its circularity and quality of the glass coat.

While winding, microwire doesn't have a strict position in space and as a result the microwire can touch the edge or fall out of laser beam and light sensor. This leads to mismatch or failed measurements of microwire. A solution for this issue would be reshape of laser beam but for small microwire, the light sensibility can be affected by diffraction processes on microwire or glass coat defects.

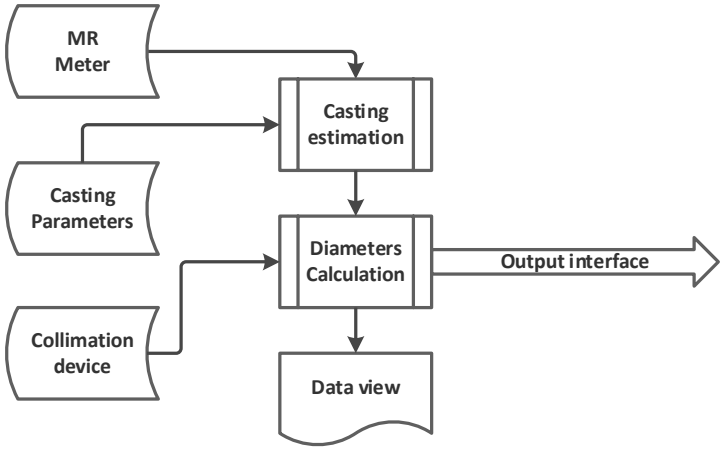

Figure 6. Microwire measurements during casting.

Considering the harsh conditions of casting and special requests for production of microwires for strain gauge sensors, a new device has been developing (Figure 6), which implements some features of the measurement method [12].

The new concept is supposed to be able to measure diameter for a wide range of microwire diameters. The most problematic to measure are the smaller microwires. For these kinds of microwires are required linear scanners with corresponding sensibility into ultraviolet and visible spectrum. The linear scanner may need some factory adjustments or sampling setup during casting. According to the proposed method, microwire diameter can be calculated according to expression:

$$D = (N_{sh} + N_{hsh}\delta_m)\, K_s \tag{3}$$

The expression above considers the average linear size of microwire diameter *D,* calculated by using linear scanner. The measured linear size is a calculated one, for both linear scanners on which the microwire is projected by a laser beam. The main argument for calculation for the expression (3) is N_{sh} which is the linear size of the shaded pixels. K_s is a noise factor, N_{hsh}- amount of half shaded pixels, δ_m – a gain factor.

Depending on microwire size, the projected shade can be dispersed, especially on the scanner aligned with winding direction. Initial aim for this scanning group was to provide a reference signal for diameter measurement. But smaller size of microwire is, more chances are that microwire can fall out of the beam for this scanning group, which leads to faulty measurements. This issue can be solved by changing the angle of the beam to microwire, but this workaround has a drawback: the quality of reference signal is decreased. To improve the measurement of the signal for the aligned microwire to beam, it was decided to use a linear scanner with improved sensibility in wide range of spectrum. This solution can provide diagnosis of measuring status by checking if the microwire shade is included into scanned area. But, especially for this scanning group, the shading effect is more evident and the sampled data for the half-shaded pixel can lead to improvement of measurement by including it in the calculation expression as N_{hsh} . Because N_{hsh} doesn't represent a strict value, a gain factor should be applied to it - δ_m. The corresponding gain factor is derived from the measured microwire diameter which is performed by MR meter during casting. The sampling on linear scanners are fast enough, but for improvement of measured data in order to obtain a more precise picture, the contrast should be increased. Increasing of contrast should be performed by software, by a digital image filter, which in the end leads to a late response. Also depending on microwire position as a result of

winding, naturally a noise is applied to the filtered signal. This noise (K_s) can be included as gain factor into calculation formula (3):

$$K_s = f(V, A) = k_v V + A, \quad (4)$$

where: V is the linear speed of winding, and A represents a set of ambient factors which reflects ambient light, environment temperature etc.

The microwire diameter measurement device (Figure 6) embeds many hardware components and stand-alone systems. The key component is the collimation device which has at least two collimation groups which use lasers in the visible spectrum (~700 nm) and two collimation groups which use ultraviolet light emitters [200 nm:400 nm].

Assembling of collimation group is a complicated process which require alignment of many components (lens, sensor, laser) and its positioning into microwire winding area. The result of alignment is not perfect and requires post adjustment which is possible to be performed digitally. As a result, a collimation group should represent stand-alone embedded device with capability of adjustments depending on assembly result and cast machine environment or setup. Thus, the collimation group should be equipped with input interfaces to assure an appropriate adjustment during casting, also it should provide the measurement of N_{sh} and N_{hsh}.

Also, an important aspect for calculation of N_{hsh} and K_s is the connectivity to casting device and the included MR meter. The required measurements and calculation are performed by casting machine, which defines it as an edge computing device, as well as diameter calculation device.

4. Non-contact application approach: a case study

The main application of SGM are the devices which basically requires contactless measurements. For these applications it is important to embed the sensible element into the body of device which is affected by elastic deformations. Considering that SGM provide strain response into its magnetic characteristics, SGM can be embedded in composite or other non-magnetic materials.

Along with structural health monitoring systems, an application example is the composite gasbags which integrity can be affected by aging or bad operation. The SGM can provide useful information to prevent or identify early potential risks of cracking on monitored devices. The proposed approach can be used in various non-contact applications where it is necessary to measure the deformations of bodies subjected to stretching, such as, for example, the detection of critical deformations in high-pressure composite cylinders. In this case, the sensor itself can be fixed on the inner lining of a high-pressure composite balloon, and the embedded device (an edge computing device) can signal a possible deformation state by scanning the surface of the composite cylinder.

Considering that developed SGM are intended to be used in environments with a wide range of temperatures (negative temperatures up to 50 °C, depending on device specific requirements), it is required to developed a prototype of edge computing device (ECD). The developed ECD, should be able to manage measurement of SGM along with magnetic response from a reference microwire which characteristics is not affected by temperature.

When the detection device approaches a body on which the sensor is fixed, the magnetic field generated by a sinusoidal alternating current (*Mag* signal in Figure 7) acts on the sensitive wire (*Smr* signal in Figure 7) and on the reference wire(*Ref* signal in Figure 7).

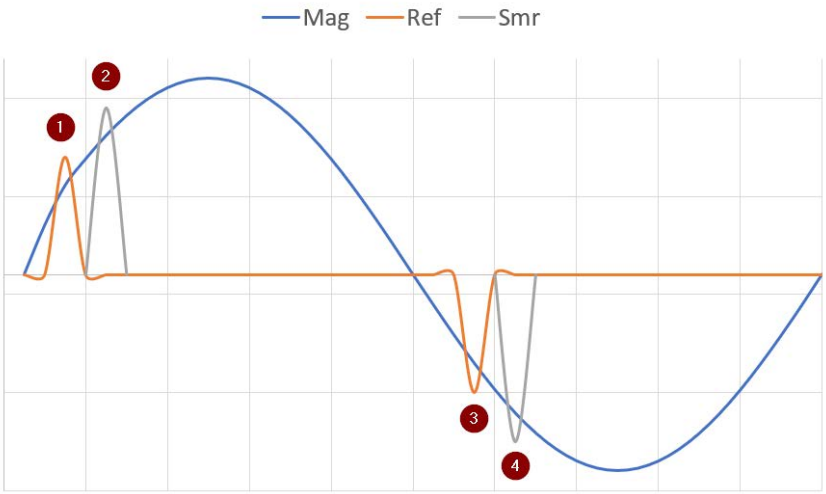

Figure 7. Magnetic response of reference and sensitive microwires.

Due to the bistable behavior upon remagnetization, the magnetic response of the sensor is characterized by a giant Barkhausen jump, which allows the induction of short electromagnetic pulses 1 - 4. Pulses 1 and 3 (Figure 7) induced upon remagnetization of the reference wire, respectively, pulses 2 and 4 (Figure 7) induced upon remagnetization sensitive wire are of sufficient amplitude to be detected by the detection device. The magnetic response of the sensor to the applied alternating magnetic field depends on the tensile strain. In other words, the change in the magnetic characteristics of the hysteresis loop is correlated with the deformation to which the magnetic material is subjected. In the case of the sensitive thread, the area of the hysteresis loop, respectively the coercive force increases with the tensile strain. At the same time, the area of the hysteresis loop, respectively the coercive force of the reference wire, does not depend on the stretching deformation. The magnetic response of the sensor can be determined by detecting the electromagnetic pulses induced upon remagnetization and calculating the numerical value of the ratio of the hysteresis loop area of the sensing wire to the hysteresis loop area of the reference wire. The resulting value must be recalculated according to the stretch sensibility coefficient of the sensitive wire with an algorithm built into the ECD. The result obtained from the calculations will represent the size of the deformation, which, in general, does not depend on the distance from the detection device (Figure 4 - sensing distance *Ds*). Thus, by applying the method of comparing the magnetic characteristics of the hysteresis loops of the sensitive wire and the reference wire, the magnitude of the deformation of a solid body can be determined (5):

$$\frac{S_{smw}^{loop}}{S_{smw}^{loop}} => \varepsilon, \tag{5}$$

where: S_{smw}^{loop} is the hysteresis loop of the sensible microwire, S_{rmw}^{loop} represents the hysteresis loop of the reference microwire and ε is the elastic strain. Considering that many parameters of the measurement device are constant or doesn't vary, the elastic strain can be calculated by using a lookup table (Figure 8), which can be adjusted during device calibration. It should be noted that such a non-contact strain sensor/device can be easily mounted on the surface of the solid body, in the example given on the inner lining of the balloon, due to the fact that the microwire segments are located close to each other and can be easily integrated into the technology existing manufacturing of high-pressure composite cylinders.

5. Predictive maintenance based on contactless sensors

The embedded SGM can provide useful information about operating conditions but the aim is to include them into complex systems designed to provide more data about the system itself. All the acquired data, along with strain measurements, can be processed by edge computing device in order to identify the system behavior patterns, which leads to certain defects or identify the required maintenance to improve costs or operations.

A new system for predictive maintenance is being designed, Figure 8. The system is supposed to implement monitoring and control of wind turbine (WT) blades. One of the key elements to provide the online state of the turbine are the SGMs that are embedded into the blades.

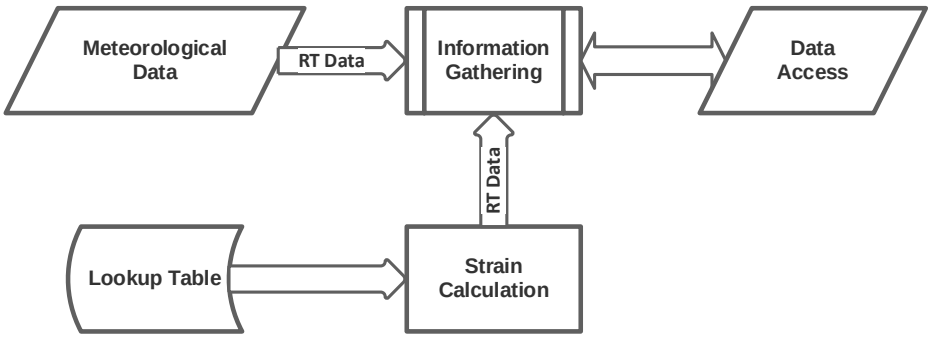

Figure 8. System for predictive maintenance.

In the above system the strain calculation should be performed in real time. Due to its complexity, these systems are built by using plug and play devices. This general criterion should be followed also by strain calculation module (SCM). Thus, the strain calculation module should represent an embedded device with corresponding to the industry input/output interfaces which would be able to provide real time data accordingly.

Embedding of microwires into blades can be a custom process in the plants, the same as installing of excitation and scanning coils for microwire. Thus, the final characteristics of the strain reading device can vary due to production process. The SGMs had a well-defined characteristic and the elastic deformation can be estimated by using a lookup table, but considering that adjustments are required, the SCM should implement an interface for calibrations and update purposes.

To implement a reliable solution for predictive maintenance all the environment factors should be considered. For WT the main inputs for prediction of the required service would be all the meteorological data. Of course, the wind power and its gusts are the main environment factors which can significantly affect WT state but there are also many other factors which in long terms has a huge impact: ultraviolet light, temperature, icing, humidity. To measure the status for all of these factors the corresponding embedded device should be implemented.

Meteorological data and SCM provide all the required real time data to an information gathering system. Depending on the scale of WT farm and purpose of maintenance, the provided data can be used combined with a cloud system which implements a predictive maintenance model, or considering the performance of modern micontrollers and its machine learning capabilities [14] or AI oriented solutions, the model can be implemented as standalone solution.

Considering the latest researches about WT blades reliability [15], the importance of the designed systems is imperative. According to research, various models were studied in order to identify the fatigue reliability or fatigue failure probability. The state-of-the-art reliability analysis was focused on two most important categories:

1) Fatigue reliability analysis calculating the probability of blade fatigue life that is greater than a target lifespan under fatigue loadings, which is difficult to estimate under complex loading.
2) Extreme reliability analysis evaluating the probability of blade performances (e.g., deflection and stress/strain) that satisfy the designed threshold under extreme loading (e.g., wind gusts). For this category the analysis is problematic due to various inherent randomness and external uncertainties that affect the fatigue life of blades.

The challenging factor for study is mainly due to the complexity of the fatigue degradation principles of blade materials, limited information available on blade fatigue experiments and the very sophisticated fatigue analysis procedure. Analysis was focused on identifying calculation methods relying on some construction aspects, abstraction of its structure (beam-like) or even identifying some key environment condition (wind gusts and its instantaneous stress) which would have a big impact on structures reliability.

Even if some identified prediction models seem to be veridical, one of the difficulties that reliability analysis of wind turbine blades faces is the lack of validation cases for the reliability analysis results due to the rare records of blade failures under all range of loadings. The background of this validation fail is the lack of blade strain measurements and elastic deformations. Thus, the developed predictive maintenance system using SGMs (Figure 8) can become also a research system for both evaluation of failure analysis and various design of blades.

5. Conclusions

Nowadays the area of sensors applications is widened along with complexity of tasks to be resolved based not only on sensors itself but also as a component of highly integrated embedded systems. SGMs are non-contact sensors and its applications are very specific. Thus, a special workflow was designed to develop the microwires depending on application. The workflow includes identifying of needed alloys, validation of casting process and methods of microwire stress annealing to provide an appropriate strain sensor. The developed SGMs provide remarkable characteristics and can be embedded into composite materials, and along with latest technologies designed for edge computing device and ML, they are suitable for predictive maintenance and failure analysis of different engineering objects and structures.

Conflicts of Interest: The authors declare no conflict of interest.

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THE OPTIMIZATION OF VIDEO TRANSMISSION QUALITY IN WIRELESS NETWORKS

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Abstract. The transmission of video stream over wireless networks is used by many applications and services, from the use of equipment in home communication networks to those carrying the video surveillance stream. Numerous technical challenges may arise when the unpredictable characteristics of the radio channel align or do not align with the stipulated requirements for transmission bandwidth and the necessary latency for transporting video data. All these challenges prevent users from experiencing smooth video streaming. Depending on the application scenarios, video service emphasis may vary according of *Quality of Experience - QoE* or parameter used traditionally in the networks, *Quality of Service - QoS*. The purpose of the research consists in optimization of the flow service, which ensures the adaptability of video communication to changes of conditions over the wireless computer network. As a result of a thorough analysis of the video playback characteristics related to the wireless channel, the most optimal approach in optimizing the quality of the video stream service over a wireless LAN requiring minimal modifications was identified, and namely system centric approach.

Keywords: *QoS, wireless network, video streaming, latency.*

Rezumat. Transmisia fluxului video prin rețele wireless este utilizată pentru multe aplicații şi servicii, de la utilizarea echipamentelor în rețelele de comunicații de la domiciliu la cele cu transport a fluxului de supraveghere video. Diverse provocări de ordin tehnic pot apărea în momentul când natura imprevizibilă a canalului radio îndeplinește sau nu cerințele fată de banda de transmisiune și față de latența necesară pentru transportul informației video. Toate aceste provocări împiedică utilizatorii să experimenteze fluxul video fără probleme. În funcție de scenariile aplicației, accentul serviciului video poate varia în funcție de *Calitatea Experienței - QoE* sau parametrul utilizat în mod tradițional în rețele, *Calitatea Serviciului - QoS*. Scopul cercetării constă în optimizarea serviciului de flux, care să asigure aplicațiilor video adaptabilitate la schimbările condițiilor peste rețelele locale fără fir. În rezultatul unei analize atente a caracteristicilor redare video referitoare la canalul fără fir, a fost identificată cea mai optimă abordare în optimizarea calității serviciului fluxului video pe o rețea fără fir LAN care necesită modificări minime, și anume - abordarea centrată pe sistem.

Cuvinte cheie: *QoS, rețea fără fir, video streaming, latență.*

1. Introduction

Video transmission through *Wireless Local Area Network - WLAN* is currently considered one of the most interesting applications of contemporaneity. As mobile data costs remain high and most users use non-wired communication, the video data transmitted over WLAN will grow. Video broadcast streaming and social video transmission encompass a category of data that is captured and delivered to end users in real-time [1].

Despite significant technological advances in recent decades, implementation advantages of mobility in the network, transmission of video data over WLAN faces multiples challenges. These challenges are distinguished by two main parameters: the wireless centric-network approach and the end-user-centric approach (based on streaming/video communication), Tabel 1 [2].

Table 1

Challenges of video streaming in wireless networks

Wireless network challenges	Challenges related to video communication/streaming
Fading	Video stream/transmission compression.
Limited bandwidth and its dynamic variation	For applications requiring real-time video communication:
Interference	The latency associated with encoding of the video data and decoding procedures.
	The computational demands of a video encoder (in terms of power consumption).

Source: Table made by the author based on [3].

In the first scenario, the QoS approach is employed to configure the network nodes in such a way that ensures the fulfillment of requirements related to data rate, latency, and packet binding. In the second scenario, end-user-centric approaches involve a collection of control techniques operating on the application layer, without requiring layer 3 OSI model QoS support [2,4].

Among the most widespread problems related to the wireless network we can mention:

Fading: this occurrence originates from multipath transmission, wherein the received signal consists of a series of weakened, phase-shifted and time-delayed duplicates of the transmitted signal.

Interference: this occurs when signals from other sources share the same frequency, typically leading to a degradation in the quality and capacity of the wireless link.

Limited bandwidth and its dynamic variation: at times, limited bandwidth and its dynamic fluctuations can occur, often due to protective mechanisms like binary exponential backoff adapted to protocol overhead and rate of transmission.

Considering that video data often consumes the lion's share of available bandwidth, especially when compared to other media types, the optimization of the video stream becomes paramount for the effective deployment of practical systems. Enabling fully scalable video streaming within the constraints of WLANs with stringent latency requirements is of considerable importance for various multimedia applications. In this context, we discuss about *Hybrid Coordination Function (HCF)* [4]. The most current challenges focused on video communication/streaming are:

Video stream compression. Uncompressed video streams require high bandwidth and generate high data rates. Reducing the redundancies of the video stream allows

compression to be achieved, and thus high bandwidth is not required, but it makes the bitstream vulnerable to errors and channel distortion. As a result, it becomes essential to employ error-tolerant techniques when transmitting compressed video bitstreams across error-prone channels, including WLAN and IP networks.

The latency associated with encoding of video data and decoding processes is a critical factor in real-time data transmission, particularly in video conferencing. While encoders of video data such as H.264/AVC provide cutting-edge compression performance, their complexity and time-consuming nature increase when employing a significant number of optimized encoders.

The computational complexity of a video encoder (in terms of energy consumption) for portable devices requires low-complexity algorithms.

All these challenges/obstacles prevent users from experiencing smooth video streaming [5–7]. Depending on specific application scenarios, the priorities for video services can vary. For instance, in video streaming platforms like Netflix and YouTube, a slight delay at the beginning of playback or transmission (typically a few seconds) is acceptable. However, in the context of video conferencing applications like FaceTime and WebRTC, maintaining an even lower delay (often less than a few hundred milliseconds) becomes crucial. This strict requirement arises because, in real-time data systems, the frame must be delivered and Protocol Data Unit (PDU) decoded precisely according to its scheduled playback time. Any retransmitted packet, resulting from excessive delay, becomes impractical when it cannot meet the stringent deadlines for decoding and display [8].

Improving the quality of video transmissions, often quantified by metrics like *Peak Signal to Noise Ratio*, is of paramount importance [9]. As such, the research endeavors to optimize the flow service, thereby enhancing the ability of video applications to adapt to fluctuations in WLAN conditions [10].

2. Technical characteristics of video transmission in non-wired networks

The challenge to transmitting real-time data over wireless channels has undergone extensive scrutiny in recent years. Video applications demand a consistent network stream while imposing stringent requirements on delay, particularly in interactive communication scenarios. Conversely, wireless channels exhibit high dynamism, characterized by rapid fluctuations in *Bit Error Rate (BER)* that can vary significantly in under a second [11].

Numerous approaches have been suggested to address the demands of secure video communication over noisy channels. These solutions encompass techniques such as *Adaptive Modulation (AM)*, *Forward Error Correction (FEC), Automatic Repeat Request (ARQ), Joint Source-Channel Coding (JSCC)* for retransmission, robust source coding, adaptive channel-source coding, data partitioning, post-processing error concealment, and scalable transport-priority coding [12–15].

A significant portion of research concerning video streaming over wireless channels has concentrated on enhancing the performance of source encoders, with minimal adjustments to network-related aspects. Nevertheless, these investigations frequently overlook the dynamics associated with the playback/recording buffer, a critical component for ensuring uninterrupted video playback. Furthermore, certain approaches within this domain entail substantial computational demands, rendering them less practical for real-time operations.

Presently, researchers are employing a multi-layer architecture to address challenges in video streaming, including issues related to data transfer, latency, jitter, and packet loss.

These challenges typically emerge due to the substantial volume of video data being streamed and the inherent characteristics of WLAN [16]. The cross-layer concept was introduced in the context of video communication over WLAN's, aiming to enhance overall system performance [17].

Rate control plays a crucial role in multimedia video streaming applications by optimizing the utilization of congested links, ensuring adequate send rates. Additionally, it safeguards against congestion collapse by moderating send rates to prevent excessive aggression. Lastly, fair rate control promotes equity among users who share shared network links [18,19].

The aim of this approach is to establish a concept of cross-layer system facilitating communication various MAC layers, enabling seamless cross-layer mapping and QoS adaptation. This approach is centered on end-systems and strives to enhance the ability of video applications to adjust to evolving wireless network conditions [20,21].

A commonly used scheme for video transmission in wired networks is referred to as *TCP-Friendly Rate Control (TFRC)*. TFRC calculates a rate by considering factors such as RTT, packet loss rate, and message size to replicate the stable and uniform performance of the *Transmission Control Protocol*. However, in wireless networks, packet loss primarily arises from physical channel errors, rendering this rate control scheme inappropriate. Neither TCP nor TFRC can differentiate between loss of packet resulting from overflow of the buffer and loss due to errors at physical layer in wireless environments [19,22,23].

Numerous attempts have been made to enhance the performance of TFRC / TCP in WLAN settings. These approaches either shield end hosts from packet loss attributable to errors in the non-wired channel or empower end terminal equipment differentiate between loss of packet arising from congestion and resulting from radio channel issues.

These proposed solutions offer rate control mechanisms at the source-to-send end system, allowing for adjustments in video coding and encoder buffer parameters to accommodate changes in channel transmission conditions. An alternative rate control method involves region-based coding, utilizing a block segmentation technique to isolate regions of interest within the source video streams and quantitatively reduce the data to be transmitted [24].

Quality-related challenges in video streaming pertain to the implementation of a rate control system aimed at preventing degradation, as measured by PSNR, which might otherwise result in a reduction of the bit rate.

This model incorporates conditional resending and employs interleaving strategy with low-delay, utilizing the encoder buffer like an integral component of the interleaving memory. PSNR metric has traditionally served as a reference point for devising these metrics. Nonetheless, certain research indicates that PSNR may not be well-suited for accurately assessing visual quality [25].

Certain authors propose a rate control mechanism founded on a stochastic model, applied prior to both the source and the priority channel [21]. In alternative research, an H.264-bit allocation rate control scheme is suggested, wherein channel throughput is assessed at the frame level and the unit base level.

Moreover, this strategy takes into account the state of the encoder buffer and the prevailing channel conditions. [26,27].

Many of these investigations tend to overlook the dynamics associated with the playback buffer, an important factor to ensure uninterrupted video playback. Additionally, the high computational demands of the proposed frameworks often render them less appealing for real-time applications.

3. Improving video streaming quality for specific services in WLANs

The basic task of an information system is to transfer a PDU from one point to another while satisfying certain QoS requirements and resource constraints. QoS requirements may include BER, *Packet Error Rate (PER)*, data transfer rate, and latency [28].

Rate control assumes a significant role modern networks, particularly in real-time video communication scenarios. It stands as one of the fundamental technologies in video encoding. The absence of rate control in any video compression standard can severely constrain its practical application [29,30].

In a standard wireless network environment, source rate control involves the allocation of radio resources among a varying number of equipment's employing a mechanism - Control Contention-Based (CCB). This characteristic, coupled with the fluctuating traffic load and BER variations, results in a bursty channel throughput pattern, as experienced by each end-user who competes for channel access alongside other stations [31–33]. ARQ (Automatic Repeat Request) suggests the retransmission of data, although forwarding is not typically favored, especially in long-distance and wireless communications, such as satellite links. In FEC, redundancy is introduced to prevent errors, where additional bits are incorporated alongside data to create encoded data. Despite this augmentation increases transmission payload and is referred to as channel coding. To enhance reliability, a combination of FEC and ARQ, known as *Hybrid-ARQ (HARQ)*, can be utilized [34]. In this context, we consider ARQ policy named stop-and-wait. This choice is appropriate when the RTP latency is shorter than transmission packet time, as is typically the case in WLANs.

Architecture and basic hypothesis. The video data transmission system's structure comprises a mobile client station, establishing communication in WLAN with the video data server. The server may either be a mobile hardware equipment or a stationary system connected through a non-wired network to the *Access Point (AP)* of the wireless channel.

Typical scenarios related to video streaming service include:

- the video source;
- the display;
- the transceiver channel;
- the encoder and the decoder;
- the corresponding buffers.

A vital element introduced in the proposed algorithm, the Rate Control Algorithm (RCA), is the source rate scheme, managed by server level. This module assumes crucial task of calibrating the source rate to its optimal value, leveraging periodic feedback associated with both channel bandwidth and playback buffer occupancy.

We presume that the core encoder possesses the capability to adapt its encoder settings in order to attain the targeted bit rate as determined by the RCA. Encoding and rate of playback, denoted as R_f, is expressed in frames per second and remains constant throughout the video streaming session. In contrast, R_{in} represents the frame reception rate at the client's end, and it fluctuates in response to changing conditions of the radio channel.

The video transmission can be real-time generated or sourced from a data archive. Once a frame of video data undergoes encoding, it is divided into one or more pieces of data, subsequently directed to the layer 2 - Media Access Control, for transmission over the radio channel. Every packet comprises a total data of $T = L + H$, where L signifies inlet bit count and H represents the error bits correction number. It is assumed that value of L remains constant for all information throughout the video session, while the H value remains consistent for all packets associated with the same real-time data frame.

For a given coding scheme, such as the BCH code, and specific pair of parameters (*L, T*), it's straightforward to determine the Bit Errors maximum number that can be corrected within PDU ($E_{max} = E_{max}(L, T)$). Additionally, the ARQ rule allows receiver transmit either a positive (ACK) acknowledgment or a negative (NAK) acknowledgment through a data channel. Depending on this feedback, the received PDU is deemed correct or not correct. In the event of receiving a NAK message, the sender will initiate the retransmission of the packet. The period required to transmit a single PDU over the channel, as well as the retransmissions number necessary for successful packet delivery to the receiver, can fluctuate over time due to line contention and variations in the Bit Error Rate (BER).

Following the adopted model, ARQ resending are overseen by the ARQ architecture, which gathers positive / negative messages from the destination and can buffer data at the encoder when retransmission is necessary. By processing incoming acknowledgments, the ARQ system is also capable of determining interval needed for successful transmission of a PDU. Specifically, when the initial attempt to transmit a packet commences, the buffer encoder sends a signal to architecture ARQ, awaiting the appropriate ACK and computing the total time duration essential for successful packet delivery. Consequently, upon the receipt of each positive acknowledgment, a response is dispatched to main module, conveying the time elapsed for sending the most recent packet. It was assumed that the ARQ messages utilize the response channel from the decoder and temporarily occupy the buffer of playback. Given that monitoring packets are compact, they can be efficiently protected with FEC, ensuring transmission error-free of responses through the channel. Consequently, the ARQ system can accurately compute the period required for successful transmission of each PDU. This information, coupled with the playback occupancy buffer, is then relayed to the source rate of the module of control.

The main goal of the approach was to maintain uninterrupted playback of video by minimizing occurrence of events of starvation within the playback buffer. To count this, the buffer starvation probability was employed as a widely accepted metric, serving as an indicator of the likelihood of buffer depletion during video playback [35,36]. To mitigate the adverse consequences of buffer starvation, efforts are directed toward identifying an appropriate startup latency configuration strategy for video stream transmission.

To accomplish the intended goal, an approach based on time windows was implemented. This method involves adjusting the coding rate of source while considering its impact over a fixed-size entire window. This strategy allows the buffer playback to accumulate packets in interval of high bandwidth, preventing starvation during time of low throughput. Consequently, this approach balances channel throughput without introducing the undesirable "saw" effect often associated with rate control frame-based. In this scheme, the axis of the time is segmented into consistent size windows, denoted as *T*. Each window is identified by an index, represented as *m*. At the outset of each window time, the module of rate control calculates likelihood of a starvation event occurring in the buffer playback during the window subsequent. Based on buffer occupancy and channel behavior information, it then establishes the coding rate of source, denoted as $R_{s,\ m}$, to be used throughout the current window. The current rate is chosen to maximize the video quality expected, ensuring that buffer starvation probability remains below the threshold desired.

The buffer starvation probability represents an important performance measure for communication network protocol design and usually occurs when the buffer is empty. The starvation is undesirable, both in real-time voice and in video stream applications. Considering buffer occupancy $(Q_m)(\tau)$, during the window identified by an index, represented as "*m*", where $0 < \tau \leqslant T$, which develops according to the following equation:

$$Q_m(Q_m) = \frac{R_f}{R_{s,m}} Y_m(\tau) - R_f \tau, \;\; 0 < \tau \leq T, \quad (1)$$

here $Y_m(\tau)$ is defined as $X(\tau + mT) - X(mT)$, where the arrival process $X(t)$, characterized as a Markovian process that tallies the accumulation of traffic arrivals reaching the rendering buffer within the interval $(0, t)$ [37].

Buffer occupancy [38,39] is determined by count of PDU within rendering buffer at the initiation time (Q_m) of the window m-th. This count is incremented by the number of PDU transmitted during the interval τ and subsequently reduced by the number of PDU rendered within the same period (1). In simpler terms, it's the disparity between the incoming and outgoing frames within the considered interval. $R_{s,m}$ signifies the Rate Bit Source Encoding for the window m-th, and this value is dictated by the control module to encoder. The control module's goal is to compute $R_{s,m}$ such that it guarantees a lower probability of buffer starvation compared to the threshold desired. Once the requirement is met, the rate maximum value is selected [38,39].

If $\Phi_m(\tau)$ denotes the probability of buffer starvation experiencing, it is imperative:

$$\Phi_m(\tau) = Pr\left[Q_m + \frac{R_f}{R_{s,m}} y_m(\tau) \leq R_f \tau\right] \leq \varepsilon, 0 < \tau \leq T, \quad (2)$$

here $0 < \varepsilon << 1$ serves as a default threshold. This equation is established separately for each interval of time within the flow, each of which equals T.

To adhere to the constraints (1, 2), Q_m necessitates specific information regarding occupancy of the buffer playback and the traffic of network anticipated in the upcoming window. The initial occupancy data is directly supplied by ARQ response loop, as outlined in the section preceding. For the initial window, Q_0 is set to N, representing the number of pre-loaded frames before initiating playback. Conversely, details about the $Y_m(\tau)$ process remain unknown, but can be forecasted based on latency transmission observed in previously sent packets, with this latency information retrieved through the return channel. Once all the pertinent data is gathered, we assign the probability $P_\tau(n)$ to denote the likelihood of successfully transmitting precisely n frames within the τ interval. Calculating $P_\tau(n)$ considers the transmission of successful $n+1$ frames, time intervals t_i ($i = 1, ..., n + 1$), resulting in the following relationships: $\sum_{i=1}^{n} t_i \leq \tau \;\; e \; t_{n+1} \geq \tau - \sum_{i=1}^{n} t_i \cdot t_i$. These relationships signify the required time to effectively transmit packet i for the server. It denotes the duration between the first attempt to transmit packet i and the moment of receiving the positive message. It's worth noting that the same frame could be transmitted multiple times within interval t_i before achieving successful reception at the destination. Assuming that t_i is independently and identically distributed, we can simplify by omitting the index i and define $f_d(t)$, corresponding to the probability density function (*pdf*) associated with t. It will also be taken into account the known $f_d(t)$ and the information about this function will be directed to a specific section. Therefore, $P_\tau(n)$ could be calculated as follows:

$$P_\tau(n) = \int_0^\tau \int_0^{\tau - t1} \dots \int_0^{\tau - t_1 \dots t_n} \int_{\tau - t_1 \dots t_n}^{\infty} \prod_{i=1}^{n+1} f_d\,(t_i)\, dt_1 \dots dt_{n+1} \quad (3)$$

Using this probability as a foundation, we can calculate *pdf* $f_{y_{\tau,m}}(\cdot)$ for $Y_m(\tau)$ process using the following relationship:

$$f_{Y_{\tau,m}}(y) = \sum_{n=0}^{\infty} P_t\,(n) \pi_{L,n}(y), \quad (4)$$

where $\pi_{L,n}(.)$ is a rectangular function that equals one within the intervals *(n-1) L ÷ nL*, with *L* representing the PDU dimension. Additionally $f_{Y_{\tau,m}}$ (.) is a function that displays piecewise continuity [38,39].

Now, let's consider that for the present window *m*, the value of $R_{s,m}$ has been set as a constant. According to (1) it results that starvation will occur whenever we have:

$$\Phi_{\mathrm{m}}(\tau) \leq \mathrm{Y}_{\tau}^{*} = \left(\mathrm{R_f}\tau - \mathcal{Q}_{\mathrm{m}}\frac{\mathrm{R_{s,m}}}{\mathrm{R_f}}\right), \tag{5}$$

and the probability of starvation will be:

$$\Phi_m(\tau) = \int_0^{Y_\tau^*} f_{Y_{\tau,m}}(y)dy \tag{6}$$

In the frame proposed in reverse, a starvation probability value is imposed and it determines the corresponding value of $R_{s,m}$. Therefore, it is initially calculated Y_τ^*, which is obtained from relationship (6), that makes $\Phi_m(\tau) = \varepsilon$ for $0 < \tau \leqslant T$. Subsequently, based on Y_τ^*, we can calculate $R_{s,m}$ according to the relationship (5).

The suggested algorithm hinges on the *pdf* availability. To ensure the efficacy of the control rate scheme, it necessitates straightforward statistical approach to forecast the *pdf* of upcoming transmissions by drawing insights from observed outcomes. Furthermore, given the time-varying nature of network characteristics, the statistical pattern of latency also experiences fluctuations.

Hence, it becomes imperative to continually refresh this data to accommodate network variations. Recent advancements have yielded several techniques for handling statistical patterns derived from observed measurements. The complete aggregation method aggregates the data into a probability distribution curve, attributing equal weight to each sample-whether old or recent. This method is straightforward in its approach, treating recent and older data with equal significance concerning their impact on the probability distribution. However, it lacks the capability to promptly respond to shifts in network traffic.

Conversely, refresh method and flush and constructs the probability curve of distribution exclusively from most recent packets, discarding older data and incurring additional overhead expenses. Implementing periodic flushing entails the complete removal of historical information, which could potentially introduce boundary effects at the flush points.

There is a necessity for a suitable statistical approach capable of forecasting future network latency by analyzing both historical and present data. This method should facilitate the monitoring, maintenance, updating, and retention of statistical patterns related to network delay.

Aging techniques. Aging refers to the accumulation of damage over time, leading to an elevated vulnerability to collapse, deterioration, or eventual failure. This phenomenon occurs due to interdependencies among components, where the failure of one component can have negative repercussions on its dependents. Recent research has been dedicated to unraveling the dynamics of these processes, revealing temporal cascades involving scaling and failure. Remarkably, these dynamics are capable of reproducing empirical survival patterns observed in various biological organisms and technological devices [40–42]. Aging techniques are applied to improve informational efficiency and thus to predict delay.

An intermediary approach is proposed here, emphasizing information storage and tracking. In this method, old data isn't entirely discarded; instead, its influence on the statistical distribution is gradually diminished. Each value within the histogram is established by counting the occurrences of packets sent within a specific latency interval. It's worth noting that a smaller recycling bin or base unit for the time interval results in a more pronounced prediction of $f_d(t)$. Conversely, a smaller bin size escalates the numerical computational complexity of algorithm (3). To mitigate the impact of older samples, each histogram bin is periodically fine-tuned, diminishing its contribution through an aging factor denoted as *F*. This operation, commonly referred to as aging, is implemented at a predefined frequency marked as *f* [32].

4. Conclusions

The introduction of (next generation) electronic communication networks, based on the IP paradigm, allows increasing network productivity by optimising resource management and increasing the attractiveness of the services offered to the user. However, the introduction of new NGN platforms should be implemented in symbiosis with the use of appropriate Quality of Service management procedures. In fact, an NGN solution, compared to the described advantages, leads to an increase in the complexity of managing QoS control tools compared to traditional network solutions.

Based on research, it was identified that the main challenge in the context of QoS optimization of video streaming over WLANs consists in network optimization method, i.e., to design a rate control algorithm, which would maximize the quality of video streaming application and channel utilization.

As a result of a thorough analysis of the video playback characteristics related to the wireless channel, the most optimal approach in optimizing the quality of the video stream service over a WLAN requiring minimal modifications was identified, and namely the end-system centric approach.

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WHERE IS ARTIFICIAL INTELLIGENCE GOING?

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Abstract: Artificial intelligence (AI) is the ability of a machine to mimic human functions such as reasoning, learning, planning and creativity. AI enables technical systems to perceive the environment in which they operate, process this perception and solve problems, acting to achieve a particular goal. The computer receives data (either already prepared or collected via its own sensors, such as a camera), processes it and reacts. AI systems are able to adapt their behaviour to some extent, analysing the effects of previous actions and operating autonomously.

Keywords: *The limits of artificial intelligence, powerful computers, how can artificial intelligence be dangerous, employment and artificial intelligence, potential future applications.*

Rezumat: Inteligența artificială (IA) este capacitatea unei mașini de a imita funcțiile umane, cum ar fi raționamentul, învățarea, planificarea și creativitatea. AI permite sistemelor tehnice să perceapă mediul în care operează, să proceseze această percepție și să rezolve probleme, acționând pentru a atinge un anumit scop. Calculatorul primește date (fie deja pregătite, fie colectate prin intermediul propriilor senzori, cum ar fi o cameră), le prelucrează și reacționează. Sistemele AI sunt capabile să își adapteze comportamentul într-o oarecare măsură, analizând efectele acțiunilor anterioare și funcționând autonom.

Cuvinte cheie: *limitele inteligenței artificiale, computere puternice, cum poate fi periculoasă inteligența artificială, angajare și inteligență artificială, potențiale aplicații viitoare.*

1. Introduction

In recent quarters, fears of a slowdown in the economy have somewhat dampened business growth rates, forcing the company to cut jobs. In the short term, customers are indeed optimising their costs. Many of them are tightening their belts and we are working with them to help them optimise their environment. But we are not seeing a slowdown in the commitments companies are making to migrate the next wave of workflows from their servers to the cloud [1].

Setting up an international body to oversee the non-proliferation of the most dangerous AI systems promises to take a long time. However, more prosaic work is already

needed to provide a framework for this technology as it exists today, with a number of burning issues to be resolved.

The success of ChatGPT itself puts the human back at the centre. Its rise is not just due to advances in deep learning, the size of its training corpus or the dizzying number of parameters: this tool was forged by learning and reinforcement with human feedback. Months of human annotation were required to ensure the consistency of the results. The human reinforcement built into ChatGPT's architecture takes several forms, including training stages on a database of annotated human queries collected since 2020, and reward system loops that penalise text generations judged to be more or less inappropriate by the annotators [2].

Finally, the fightback is being organised to detect texts generated by an AI. The GPTZero online service, for example, is preparing a dedicated offer for education professionals, and OpenAI is working on a "statistical watermark" applied when text is generated. Cheaters be warned.

Regulating artificial intelligence (AI) is no longer an option. It is a necessity. The spectacular success of the chatbot ChatGPT, launched at the end of 2022 by the company OpenAI, has given the general public a taste of the range of possibilities offered by this technology.... for better or for worse. One of the main merits of the initiative has been to accelerate awareness of the imperative need to establish a framework for the development of AI. The question now is what form this regulation should take and how it can be applied at global level [1-3].

2. ChatGPT

ChatGPT is attracting a lot of attention in the professional world, from businesses to the self-employed, all of whom see it as a way of boosting their productivity. And yet, AI is still in its infancy and has come a long way in just a few months! The possibilities seem to be multiplying, particularly with the release of GPT-4, a more reliable and accurate version of the language model that powers the chatbot, and the integration of plug-ins into ChatGPT. Productivity tools are already undergoing changes: Microsoft has announced the arrival of the Copilot assistant for its Microsoft 365 suite, Google is preparing to add an intelligent assistant to its Workplace suite, and even Canva is continuing to integrate more and more AI into its tools via the Canva Visual Suite [4].

AI is gradually creeping into the world of work and seems destined to eliminate many of today's jobs. According to a survey by *ResumeBuilder, reported by Fortune*, 25% of companies have already replaced employees with ChatGPT - as in the case of the media company CNet, for example. It's a real revolution for service sector jobs, just as industrialisation was for manual professions, and one that will particularly affect Europe and the United States. So what changes can we expect?

3. Employment and AI: a revolution for the service sector

In a blog post, Bill Gates calls it the most revolutionary technological advance since the *graphical user interface* (GUI) was introduced in 1980. "The development of artificial intelligence is as fundamental as the creation of the microprocessor, the personal computer, the Internet and the mobile phone. It will change the way people work, learn, travel, treat themselves and communicate with each other," he says. For the first time in the history of technological innovation, it is the so-called "intellectual" professions that will be most

affected. This change has been studied by a number of specialists, who are trying to predict the impact that this technology could have on the employment sector in the years to come [5].

Will photography generated by artificial intelligence algorithms, with its hybridisation and recombination of millions of pixels from source images, be a creative tool in a future virtual pact? Or will it open the door to the worst plagiarism and unfair competition on a massive scale?

4. Breaking a lance for humans

Artificial intelligence producing artists is the latest spectacular development in the field of AI. This raises fears and expectations. But what are the limits of what artificial intelligence is capable of?

Artificial intelligence is becoming more and more important in everyday life. AI was also widely used at the last World Cup in Qatar. More than 15,000 cameras were deployed around the eight football stadiums to predict and prevent dangerous crowds and possible mass panic. Likewise, video surveillance helped referees make tricky decisions. The footballs themselves were equipped with sensors that input the position of the balls five hundred times a second [6].

After artificial intelligence was not yet a topic after the turn of the millennium, its development picked up considerably in the 2010s. Great progress was made in autonomous driving, in the diagnosis of illnesses, in the coordination of processes, in logistics and finally AI was also able to beat the reigning world champion in the game of Go, a task that had been considered impossible only a short time before.

5. Powerful computers as a prerequisite

However, all these successes are based on the fact that modern computers can process a huge amount of data - and not least because of this, a huge amount of new data is constantly being generated that is reused by the computers using algorithms. That's what's behind Big Data. In fact, however, a learning and analysing AI is completely "stupid". In order to understand what a cat is, the AI has to be fed with millions of cat pictures, whereas a small child very quickly understands what a cat is [7].

6. In the sense of a learning process

Good examples of how large amounts of data can be optimally used and maintained thanks to AI are provided by the B2B platforms "who delivers what" and euro-pages. The platforms offer a large amount of information to bring commercial buyers together with the right products and services. As the carrier of the two platforms, the company *Visable* uses AI programmes to maintain the data (for example to provide keywords for the data search or to eliminate data duplicates. This requires the availability of high-quality data. After all, data quantity is not the same as data quality. For data collection, *Visable* has started to use artificial intelligence to identify relevant data as such - in the sense of a learning process via intelligent algorithms [5-7].

Artificial intelligence thus works comparatively inefficiently. It does not succeed in distinguishing between relevant and irrelevant data on the basis of a so-called low level of prior knowledge. Artificial intelligence has no knowledge in this sense and does not know what knowledge is. It only operates with data. *AlphaGo*, which beats the Go world champion, does not know what Go is, nor that it is a game, and does not know any emotions

and mental states associated with a game such as adaptation, fascination or the joy of victory [8,9].

7. The fightback is getting organised

ChatGPT can help with the first draft when you're faced with a blank sheet of paper, but after that you still have to write and give it a style. ChatGPT partly reverses the teaching philosophy. This time, the students themselves have to question the machine. It's an opportunity for us to see how the students carry out the tasks we give them, to get them to work on fact-checking, and to check that the bibliographical references generated are correct. Banning the tool is "counter-productive" in any case, as it reinforces students' desire to use it. As with the arrival of Wikipedia and search engines, the challenge for teachers is to "experiment with the limits" of these tools [10-11].

8. Great Britain initiative

British Prime Minister Rishi Sunak's initiative on Thursday 8 June 2023 to organise the first global summit on AI in the UK within the next few months shows that this is no longer just a technological issue, but a highly political one. Taking advantage of a meeting with US President Joe Biden, Mr Sunak is making a date to avoid finding himself isolated at a time when, each in their own way, the *European Union* (EU) and the United States are expressing their desire to regulate AI.

A regulation is due to be adopted by the European Parliament, before being the subject of negotiations with the *Council of the EU* and the *European Commission* with a view to reaching a consensus in a few months' time. At this stage, the American approach is more limited, focusing on corporate responsibility [9-12].

9. Current uses of artificial intelligence

We tried to have a philosophical discussion with a chatbot; we talked about how human beings can preserve their autonomy, their independence, at a time when artificial intelligence is becoming ever more powerful. ChatGPT used relevant concepts such as human dignity, transparency and fairness. However this is far from a deep philosophical dialogue. ChatGPT hasn't really positioned itself, but we're using it in the AI [13-15].

The most recent AI models are causing upheavals on a mythological scale. We cannot be content with small adaptations; we must change the way we create, compete, collaborate, learn, govern and deceive, commit crimes and wage war.

10. Jobs at risk?

Tech companies are investing heavily in AI development, and Google alone has 20 AI-powered projects in the pipeline for 2023 alone. This comes on the cusp of recent mass layoffs from Amazon (27,000), Meta (21,000), and Google's parent company, Alphabet (12,000) [16].

Do these numbers signal increased job losses in favor of developing advanced AI in the near future? Possibly—the idea of automated systems to handle monotonous workloads or entire projects isn't out of the question. We've done it time and time again for centuries. Where would we be without the industrial revolution, the development of vaccines, and the technological advances that place computers in our pockets?

So, is it possible for engineers to be replaced by AI-driven systems? Yes, but it's not likely to happen any time soon. According to a 2016 report from *Stanford University*, there's

no imminent threat of workers being replaced, but rather AI will be developed to provide useful apps to help those workers. Although routine work and simple tasks may be automated, there's enormous potential to benefit engineers in every field [17].

Those with a STEM [(*Sciences, Technology, Engineering, and Mathematics*), is centred on education in these disciplines] background will still be in high demand, and many jobs will require human/computer collaboration. Software engineers will be needed to create and test AI systems, and advanced AI will allow engineers to become more efficient and solve a wide range of issues. That said, only time will tell if AI will replace the engineering job pools or be used as an invaluable tool to assist in project creation [15-17].

11. Artificial intelligence: low-intensity threats

Exploiting bias: taking advantage of existing biases in algorithms, for example YouTube recommendations to channel viewers or Google rankings, to improve product profiles or denigrate competitors.

Robot burglars: using small autonomous robots that slip into letterboxes or windows to retrieve keys or open doors. The damage is potentially low, as it is very localized on a small scale [17-19].

Blocking detection by AI: thwarting the sorting and collection of data by AI in order to erase evidence or conceal criminal information (e.g. pornography).

Fake reviews written by AI: generate fake reviews on sites such as *Amazon* or *TripAdvisor* to harm or favor a product.

AI-assisted tracking: using machine learning systems to track an individual's location and activity. Counterfeiting: making fake content, such as paintings or music, that can be sold under false authorship. The potential for harm is relatively low, as there are few known paintings or music.

12. Conclusions

AI means many things to different people. Currently, AI is used for information and automation and has minimal learning capabilities. We are many years away from a fully self-aware AI program. All levels of AI carry risk. The primary AI programs are mainly a risk to skilled labor. Higher-level AI could post real dangers to humanity. The benefits of AI continue to grow, which will ensure that the technology is here to stay. Businesses and society as a whole will need to learn to use the new technology and make adjustments. Companies will need to incorporate AI to remain competitive, and workers may need to change their skill set to retain employment. As AI technology continues to evolve, questions concerning issues such as legal liabilities will continue to surface. Private investment in AI has soared while investment concentration has intensified:

Private investment in AI in 2021 was approximately $93.5 billion, more than double total private investment. investment in 2020, while the number of newly funded AI companies continues to decline, from 1051 companies in 2019 and 762 companies in 2020 to 746 companies in 2021. In 2020, there were 4 funding rounds worth $500 million or more; in 2021, there were 15. The US and China dominated transnational AI collaborations: Despite rising geopolitical tensions, the US and China recorded the highest number of collaborations in AI publications from 2010 to 2021, up five-fold since 2010. Collaboration between the two countries produced 2.7 times more publications than between the UK and China - the second highest on the list. In other areas it is hard to measure performance when there has not been significant progress, like in commonsense reasoning.

In 2021, China continued to lead the world in the number of AI journals, conferences and repositories published (63.2% more than the US). The US held a dominant lead in terms of number of conferences and references on AI citations. Chinese tech giant Alibaba has launched an artificial intelligence tool that can generate images from text, CNBC reports.

Tongyi Wanxiang allows users to enter requests in Chinese and English, and the AI tool will generate an image in different styles, such as a sketch or a 3D cartoon. Alibaba's cloud division, which launched the product, said it is available to enterprise customers in China for beta testing. Tongyi Wanxiang is Alibaba's latest generative artificial intelligence offering, as tech giants in China and the US look to advance the technology.

Generative AI refers to a type of artificial intelligence that is able to generate content based on requests. It is trained on huge amounts of data to be able to do this. The most famous example is OpenAI's ChatGPT, which has sparked a race from the biggest players in tech to develop their own chatbots.

In the US, Google launched its AI chatbot called Bard. And in China, Baidu launched Ernie Bot and Alibaba launched Tongyi Qianwen. There are already AI text-to-picture services available at the moment. From 2010 to 2021, collaboration between educational and non-profit organisations produced the largest number of publications on AI, followed by collaboration between private companies and educational institutions and between educational and government institutions. The number of AI patents filed in 2021 is more than 30 times higher than in 2015 (annual growth rate of 76.9%).

For most machine learning specialists, the problem today is not the lack of research, tools or new techniques, but the fact that they can't keep up with all these advances!

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LAND-USE AND TRANSPORT INTEGRATED PLANNING AND MODELLING IN CLUJ-NAPOCA, ROMANIA

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Abstract. The paper presents an example of successful reconversion of an industrial site located in the built-in area of Cluj-Napoca, Romania. This case study shows that land-use and transport integrated planning can be effectively implemented when a transport-oriented development (TOD) is designed for the redevelopment of an industrial site. Using TOD principles identified in the Romanian law and the technical criteria identified in the scientific literature, Sanex platform is analyzed to demonstrate it is a TOD. This would be the first documented TOD designed in Romania. A model is developed for TOD Sanex to estimate the impact that the redevelopment of the industrial platform into a multifunctional area will have on the local traffic. In this regard, two scenarios are analyzed – present scenario and future scenario after completion of the redevelopment. Two variants of the future scenario are discussed in connection to the Northern Mobility Corridor (CMN), the main project in implementation in the area, which is designed as a complete street. The results demonstrate that the induced traffic wouldn't have a considerable impact on the local traffic now or in the perspective of the redevelopment. It can be integrated by the street network, which could operate in appropriate conditions. Considering the need of revitalization of the urban and rural industrial sites at the national scale in Romania and the benefits of TOD, a methodological framework in four steps is proposed. This framework would be a helpful support in the sustainable urban reconversion process, especially to achieve the reduced impact over the built environment and urban mobility.

Keywords: *Brown field redevelopment, industrial site revitalization, Sanex platform, transit-oriented development, urban densification.*

Rezumat. Lucrarea prezintă un exemplu de reconversie reușită a unui sit industrial intravilan din Cluj-Napoca, România. Acest studiu de caz arată că planificarea integrată a utilizării terenurilor și a transportului poate fi implementată eficient atunci când o dezvoltare orientată către transport (TOD) este proiectată pentru reamenajarea unui sit industrial. Folosind principiile TOD identificate în legislația română și criteriile tehnice identificate în literatura științifică, platforma Sanex este analizată pentru a demonstra că este un TOD. Acesta ar fi primul TOD documentat, proiectat în România. Este dezvoltat un

model pentru TOD Sanex pentru a estima impactul pe care reamenajarea platformei industriale într-o zonă multifuncțională îl va avea asupra traficului local. În acest sens, sunt analizate două scenarii – scenariul prezent și scenariul viitor după finalizarea reamenajării. Două variante ale scenariului viitor sunt discutate în legătură cu Coridorul de Mobilitate de Nord (CMN), principalul proiect în implementare în zonă, care este conceput ca o stradă completă. Rezultatele demonstrează că traficul indus nu ar avea un impact considerabil asupra traficului local, în prezent sau în perspectiva reamenajării. Poate fi integrat prin rețeaua stradală, care ar putea funcționa în condiții adecvate. Având în vedere nevoia de revitalizare a siturilor industriale urbane și rurale la scară națională din România și beneficiile TOD, se propune un cadru metodologic în patru pași. Acest cadru ar fi un sprijin util în procesul de reconversie urbană durabilă, în special pentru a obține un impact redus asupra mediului construit și a mobilității urbane.

Cuvinte cheie: *Reamenajare câmp brun, revitalizare sit industrial, platformă Sanex, dezvoltare orientată spre tranzit, densificare urbană.*

1. Introduction

The redevelopment of brown fields and old industrial sites in Cluj-Napoca represents one of the main goals of the local administration in the densification process of the city to reduce the urban sprawl phenomenon. During the last three decades the city has generated a very important urban sprawl effect in Cluj metropolitan area as documented in previous research [1-13]. The main actors that are addressing the issue of brownfield and industrial sites redevelopment [14-19] are joining their forces in supporting Public-Private-Partnership investments [20-22], to spotlight the opportunities for land reuse and urban regeneration [23-33].

However, land reuse, such as transforming the industrial platforms into multifunctional urban spaces generates additional trips in the transport system, both within the area of the development but also in connection with the city. Using integrated land-use and transport planning tools, such as transport-oriented development (TOD), proves to be a successful means to reduce the growing pressure on the transport system and to integrate additional trips [34].

Planners in different regions are successfully using TOD, considering elements such as physical design, transportation, environment, social, economy, collaborations, and accessibility in their urban regeneration projects [35-37]. TOD planning strategies support sustainable urban growth, based on some common general principles including PT efficiency, land use diversity and density, accessibility, connectivity, and sensitivity to property values [38,39].

The densification of the urban area implemented in neighborhoods surrounding specific transport hubs is at the core of TOD concept, promoting the compact and mixed land use well-integrated with mass transit [40]. The densification of mixed urban activities in the proximity of public transport facilities, between 400 - 800 m, supports two major main benefits. Creating a compact and dense urban form favors the reduction of the trips number and length shortening for the purposes served by the activities of the newly developed area while increasing the desirability of using public transport for out-of-area trips reduces the urge to use private cars [41,42]. In this regard, the location the development within a short walking distance of high-quality transit becomes the most important aspect. The ideal distance is 500 m of actual walking distance (about a 10-minute

walk) or less, including all detours, from rapid, frequent, and well-connected public transport service. However, this should not be more than 1,000 m, about a 20-minute walk [43].

According to the Romanian law on sustainable urban mobility [44], a final version which is under debate, TOD is described as "the design and realization of urban spaces to integrate communities, activities, buildings and public space, with the provision of easy connections through walking and cycling, as well as the provision of efficient public transport services to the rest of the city" [44].

The document of the law also defines TOD principles. They include the design of dynamic public spaces, ensuring inclusive mobility, adequate and safe infrastructure for pedestrians and cyclists, as well as of public transport that can compete with the private car, to the densification of activities around public transport stations in a mix that allows access to quality public transport and the reduction of the number of trips, as well as the reduction of travel times through the proximity of workplaces, educational offer near homes[44]. TOD principles are listed in the following section.

The paper aims to demonstrate that the redevelopment of the Sanex platform follows the principles of a TOD, on one hand and to estimate its impact on the local traffic, on the other. The location of the site in proximity to mass-transit and the integrated planning of the platform serve the purpose to best accommodate additional trips and to ease the burden on the transport system. Furthermore, the Public-Private-Partnership investments prove their capabilities to support sustainable urban regeneration.

Section 2 of the paper presents data collection and the methodological framework in four steps. Section 3 of the paper presents the practical results and elaborates the discussion based on the results. Section 4 synthesizes the conclusions.

2. Data collection and methodological framework

TOD characteristics of the Sanex platform are presented and verified based on the principles highlighted in the Romanian law in Figure 1 [44], which considers the needs of all users of the transport system. Spatial analyses are conducted using ArcGIS.

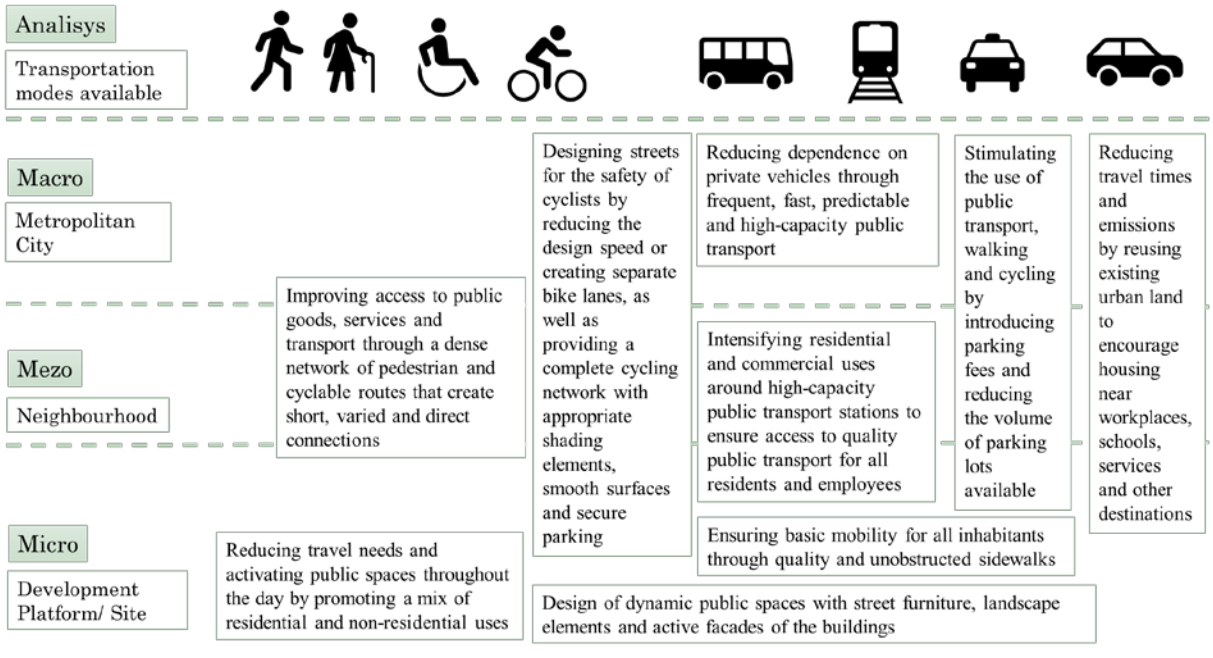


Figure 1. TOD principles according to Romanian law [44].

Furthermore, the impact of Sanex development on the local traffic was estimated following the four steps presented in Figure 2: traffic analysis, trip generation analysis, model development and analysis for the estimation of TOD Sanex impact on the local traffic.

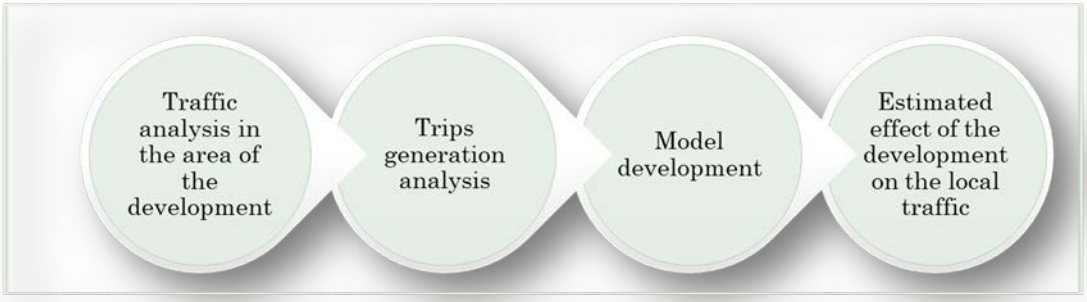


Figure 2. Estimation of the impact of TOD Sanex development on the local traffic.

The analyses are based on extensive traffic measurements conducted in 20 representative intersections and on 13 street links which were established by the municipality, Figure 3. Automatic data collection was conducted during May - June 2022 (05.23.2022 - 06.06.2022), within a period considered representative in the municipality during the school and academic semester.

Traffic flows were determined using video recording with MioVision Scouts and video processing for 12 hours between 7:00-19:00 on each of the 20 intersections. 20 O-D matrices were obtained on each category of vehicles. Traffic data on each link were determined in volumes of passenger car units (PCU).

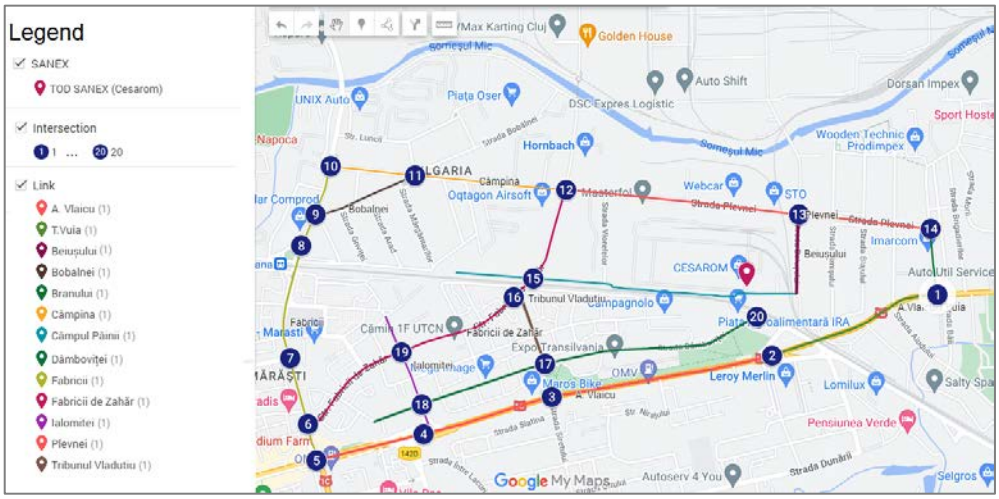


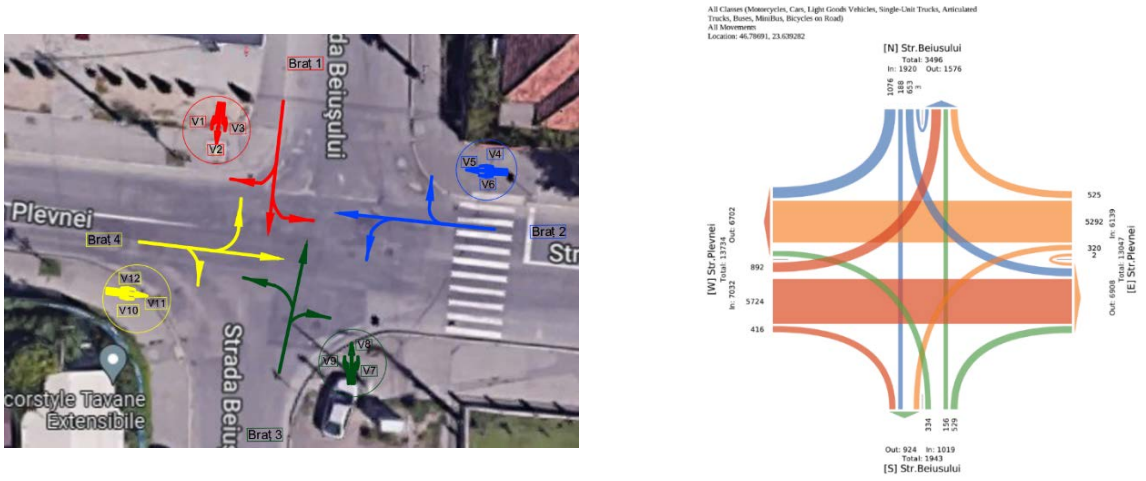
Figure 3. Intersections and links for traffic counting established by the local administration in the proximity of the redevelopment site (Basemap: Google Maps).

Figure 4 presents an example of an analyzed intersection, I13, with the traffic movements (Figure 4a) and traffic flows (Figure 4b).

There is only one access point for the Sanex platform at the moment, through the Intersection 13 (I13) from Plevnei Street, through the streets Beiușului and Câmpul Pâinii.

Arcady/picady was used to evaluate the level of service of each intersection and the delays. Traffic volumes on each link were obtained from O-D matrices. The traffic capacity on each link was evaluated with the aid of the Romanian standard [45]. The volume/capacity ratio (V/C ratio) of the links was used to compare the results obtained for different scenarios.

Both intersections and links were analyzed in two scenarios - the existing situation and the perspective in which the investment would be completed. Two variants of the future scenario are discussed in connection to the Northern Mobility Corridor (CMN), the main project in implementation in the area, which is designed as a four-lane complete street.



a) b)

Figure 4. Intersection I13 movements: a) with the traffic movements; b) with traffic flows.

The traffic analysis in the development area was followed by the trip generation analysis. The calculation of the hourly traffic flows generated / attracted by the new development was based on the ITE Trip Generation Manual [46], 11th Edition.

Peak hour volumes are calculated by multiplying the number of parking lots by the hourly distribution of entering and exiting vehicle trips by land use. On the site there are parking spaces, which generate/attract traffic and which can be found in the traffic counts which were carried out.

The results were used to develop the traffic model for a 12-hour period. It was used for the traffic capacity verification of the links and the intersections, at the peak hour resulting from the model. The last step was to estimate the impact of TOD Sanex development on the local traffic using the attracted/generated traffic in both scenarios and variants.

3. Results and discussion

The reconversion of the Sanex platform was analyzed as a case study of TOD, a land-use transport integrated planning tool. The planning process considered the connection to the transport system as well as the reconversion of the activities on the platform. Therefore, the characteristics of the redevelopment were checked according to TOD principles. Furthermore, the impact of TOD on the local traffic was estimated.

3.1. Sanex platform connections to the transport system

Sanex platform is located north of the railway corridor in Cluj-Napoca. This urban area is in a massive process of redevelopment by restructuring the industrial platforms, into mixed urban areas (residential, shopping/services, business, leisure etc.). A great advantage is that the area is well integrated into the transport system, with good accessibility to the existing facilities of public mass transport in its proximity.

The existing bus stop on Plevnei facilitates two lines 36B, 52 and the IRA hub facilitates 8 bus and trolleybus lines as well as 6 metropolitan lines.

It also has great connection to proposed projects in the area such as the northern mobility corridor (Coridor de Mobilitate CMN in Figure 5), the metropolitan train (Tren metropolitan in Figure 5) and the metro (Metrou in Figure 5) through the intermodal node (Nod intermodal in Figure 5) which will be located at the junction of those major projects, in the future.

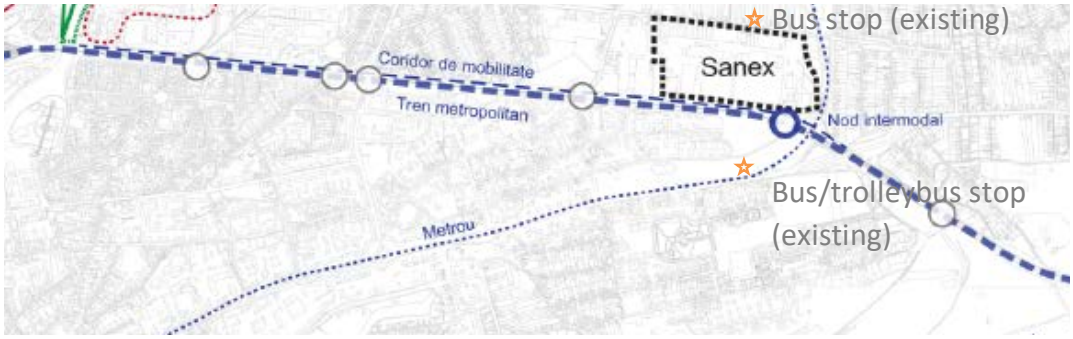


Figure 5. Sanex platform connections to the transport system.
(Source: project manager).

CMN is designed as a complete street from IRA Node to the Railway Station Square on both sides (north and south) of the railway and including it. The implementation of the Sanex project also includes the construction of the first section of CMN, from the western side of the platform to the IRA node which is partially included, and which implies a partial completion of CMN north of the railway (noted as Sanex CMN in Figure 6). This segment is the object of a Public-Private-Partnership investment.

Figure 6. Two variants of the future scenario - Sanex CMN and Complete CMN.

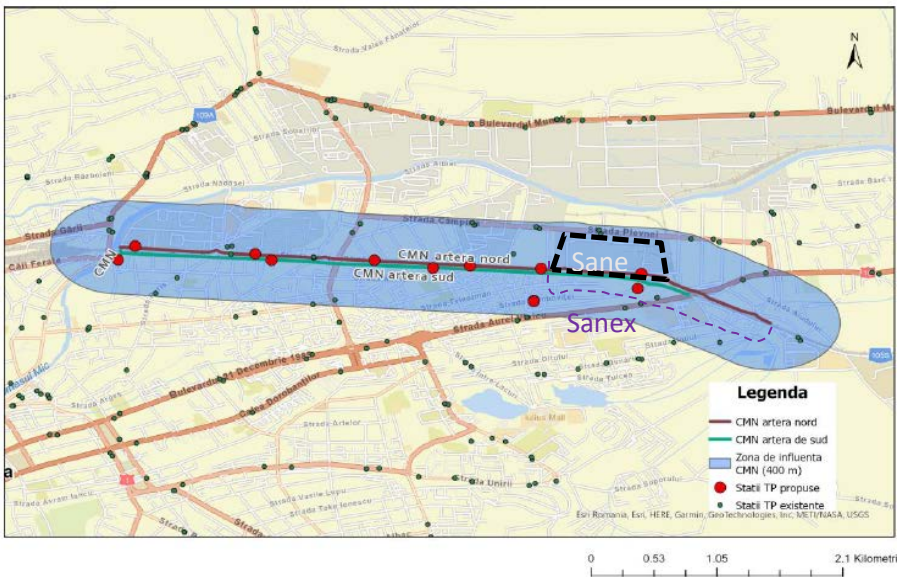


Figure 7. Public transport facilities development in correlation to CMN.

Upon completion of CMN, it will ensure direct auto connection of the platform to the main transport artery of the municipality (East – West), as well as to the CMN Railway Station Square.

Sanex platform is located between two transport arteries. The southbound limit is Câmpul Pâinii Street, which is going to be integrated into CMN, a four-lanes complete street. The northbound limit is Plevnei Street located on a secondary traffic artery of the city. Sanex CMN will provide direct connection to Traian Vuia – Aurel Vlaicu, four-lane streets on the main transport axis of the municipality running from East to West providing a good connectivity in the transport system.

CMN's area of influence of 400 m includes Sanex platform entirely (Figure 7). Sanex platform benefits from the facilities of mass public transport existing in the proximity which are symbolized with the green dots in Figure 7. CMN implementation will ensure increased PT efficiency and accessibility through the proposed public transport facilities symbolized with red dots in Figure 7.

3.2. Sanex platform reconversion activities

The site has a total area of 230.551 sqm of industrial and quasi-industrial activities considered in the urbanistic reconstruction planning (Figure 8).

It is planned to accommodate high density mixed urban functions - collective housing (31% of the built-up area), shopping center (55% of the built-up area), buildings and spaces for offices and services (5% of the built-up area), proximity facilities for servicing the residential area (education, recreation, sports, health, social services, leisure and parking, 9% of the built-up area).

The platform and some adjacent lands are considered in the urban planning process to provide convenient and efficient access to a diverse combination of land uses (Figure 9). Accessibility of TOD Sanex will be improved from one indirect access point on Branului Street to 4 direct access points to the main bordering arteries – two intersections on Plevnei Street and two roundabouts from CMN Sanex, directly connected to the East-West transport axis (Aurel Vlaicu- Traian Vuia).

TOD Sanex will be served by its own network of public spaces (predominantly pedestrian) and green spaces. The new design plan aims to increase the walking and cycling in the area by creating bike lanes and walking spaces along streets running northbound the platform, separated from the general flow. The street running across the platform from West to East is designed as a shared space with occasional car traffic. With the realization of the Intermodal Node (Nod intermodal in Figure 5), the restructuring of the Sanex complex will make possible a new pedestrian corridor between Someș River and the East Park of the municipality, supporting the development of a high-quality urban public space.

The modal share in the proximity of the redevelopment site (Table 1) shows a reduced cycling rate. The implementation of TOD Sanex would help improve this situation.

Table 1

Percentage in the modal share in proximity of the redevelopment site

Street	Bicycles, %	Heavy traffic, %
Aurel Vlaicu	0.1	6.0
Traian Vuia	0.2	4.9
Plevnei	0.7	8.7
Beiușului	1.5	6.0
Câmpul Pâinii	0.1	7.1

Parking places are located in a dedicated building adjacent to the shopping center and office buildings, with great respect for the green areas dedicated to sports and leisure. Some residential parking places are located mainly in the underground of the residential buildings area. The total number of parking places is presented in Table 2.

Table 2

Parking places available on the site

Total number of parking places	5.606
Commercial	2.650
Offices	800
Residential	2.156

New bus lines with several new bus stops would help reduce car dependency, especially in connection to the railways station square which would help visitors to use reliable transit.

Thus, TOD Sanex will concentrate the mixed-use area of high density within a radius of up to 800 m from the mass public transport facilities, respectively 5-10 minutes of walking and will ensure increased pedestrian accessibility by reducing the area of land dedicated to cars. The availability of multiple activities on the platform is a magnet for inner movements, turning into a reduction of trips in connection to the city.

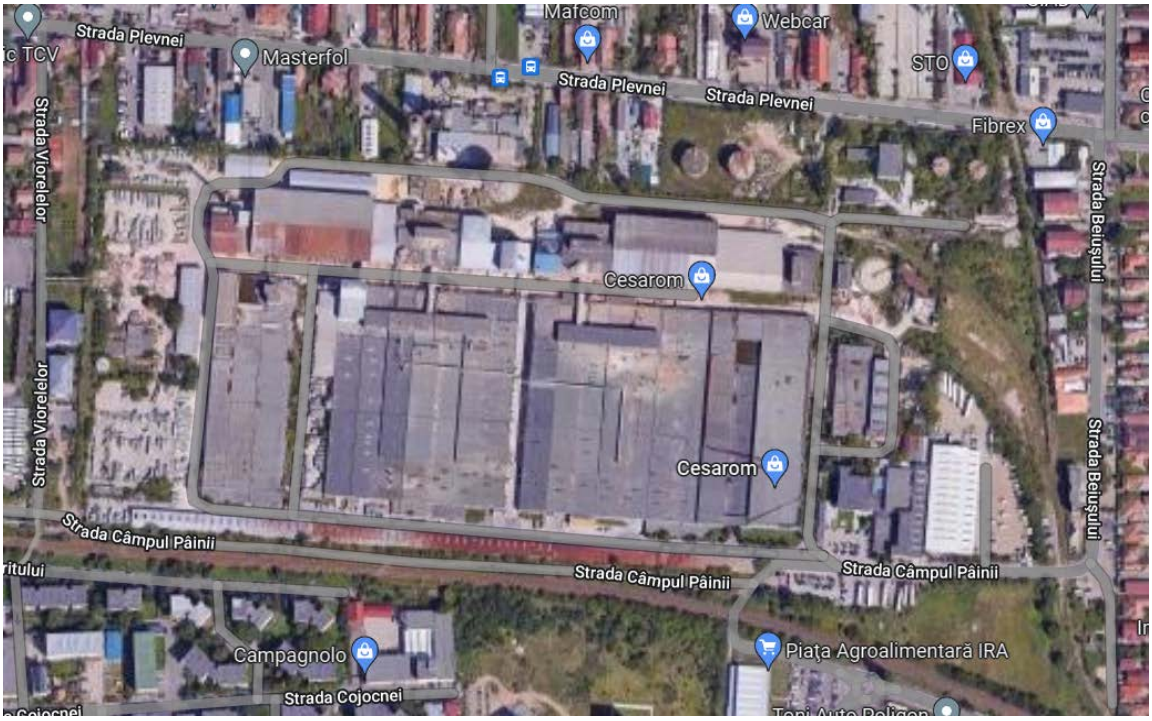


Figure 8. Sanex platform (aerial view, Google maps).

The redevelopment process is planned to embed the needs of all people and users of the transport system [44]:

- Ensuring basic mobility for all inhabitants through quality and unobstructed sidewalks.
- Design of dynamic public spaces with street furniture, landscape elements and active facades of the buildings.

- Designing streets for the safety of cyclists by reducing the design speed or creating separate bike lanes, as well as providing a complete cycling network with appropriate shading elements, smooth surfaces and secure parking.
- Improving access to public goods, services and transport through a dense network of pedestrian and cyclable routes that create short, varied and direct connections.
- Reducing dependence on private vehicles through frequent, fast, predictable and high-capacity public transport.
- Stimulating the use of public transport, walking and cycling by introducing parking fees and reducing the volume of parking lots available.
- Intensifying residential and commercial uses around high-capacity public transport stations to ensure access to quality public transport for all residents and employees.

Figure 9. Zonal Plan of SANEX platform restructuration [47].
Source: Planwerk.

- Reducing travel needs and activating public spaces throughout the day by promoting a mix of residential and non-residential uses.
- Reducing travel times and emissions by reusing existing urban land to encourage housing near workplaces, schools, services and other destinations.

Therefore, it is clearly demonstrated that the design of the Sanex industrial site revitalization follows TOD principles stated in the Romanian law. The integrated planning process of the newly designed activities with the transport system is a great tool for sustainable urban growth.

3.2. The estimation of the impact of the Sanex platform development on the local traffic

Firstly, an analysis of the local traffic was carried out. The analysis was performed for all links as well as for all the intersections. For the aim of the paper, the situation on the streets and in the intersection adjacent to TOD Sanex was presented.

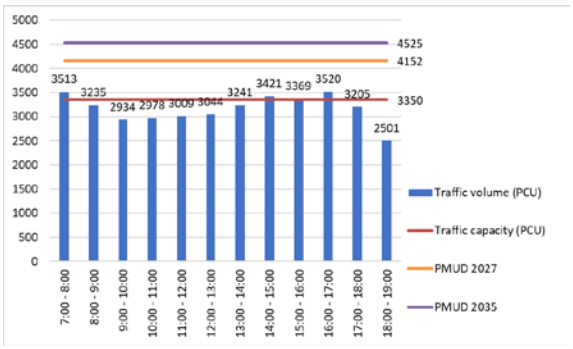
Traffic data for all intersections and links were analyzed in the present scenario and in the perspective in which the investment object would be completed. Two variants of the future scenario were considered in connection to the Northern Mobility Corridor (CMN): Complete CMN (Railway Station Square to IRA node) and Sanex CMN (first section of CMN, from the western side of the platform to the IRA node which would be included).

In the present scenario, three analyzes were carried out for each link to determine traffic volume by vehicle category, hourly traffic volumes in relation to the traffic capacity (V/C ratio) of the sections (Figure 10), respectively the volume of directional traffic on each section.

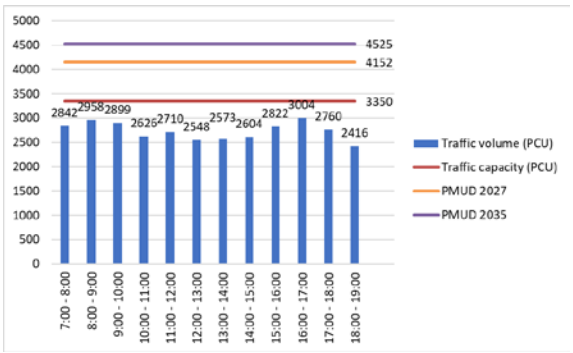
The estimations of the traffic capacities for 2027 (PMUD 2027) and 2035 (PMUD 2035) used in Figure 10 were found in the urban mobility plan of Cluj-Napoca (PMUD [48]). These values emphasized on the efforts of the municipality that had already planned for short- and medium-term developments in the transport system in accordance with the aim of redeveloping the industrial platforms in the northern area of the municipality.

The capacity of all analyzed streets in the extended model was exceeded only for Aurel Vlaicu Street by a maximum of 5%, in 4 hourly intervals which did not represent a major problem. The Romanian standard clarifies that only the links in street network with higher V/C ratio than 25% during peak periods should be considered for improvements.

Aurel Vlaicu Street

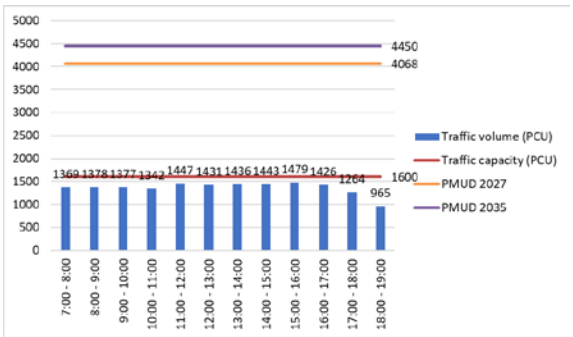


Traian Vuia Street

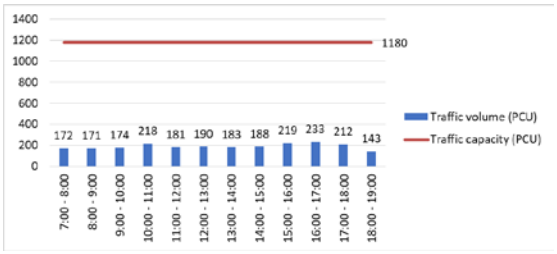


Plevnei Street

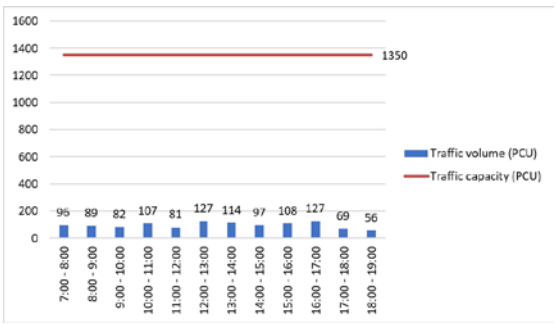
PMUD analyzed the future scenario in which the street would have four lanes.



Beiușului Street



Câmpul Păinii



The street is made up by several disconnected sectors. CMN will be developed over them. CMN Sanex will develop over one segment that is bordering Sanex platform in South, the other segments which are remote remaining in place.

Figure 10. The characteristics of the adjacent street network in the present scenario – the existing situation

(Foto source: Google maps).

Secondly, the trip generation analysis was conducted. The results were used to estimate the impact of TOD Sanex construction on the local traffic through the attracted/generated traffic.

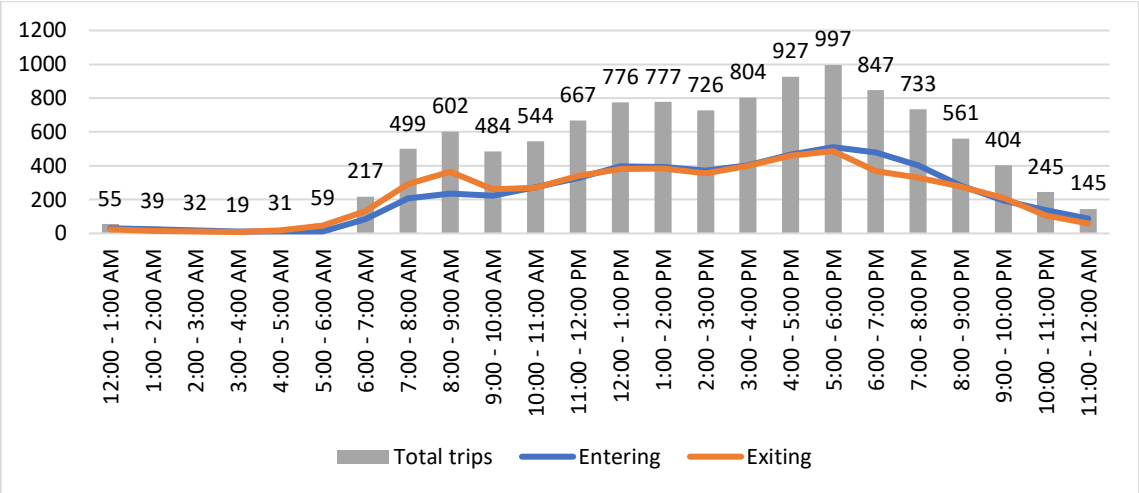


Figure 11. Attracted/generated trips.

These values correspond to a significant traffic intensity of 997 PCU in the peak period of 5-6 pm (Figure 11), which must be integrated into the existing traffic flows in the transport network, using all four access points in the perspective in which the investment would be completed.

CMN was designed as a complete street. The corridor transverse profile is shown in Figure 12. In order to be operational, CMN needs to be entirely built, including the dual carriagway on the both sides of the railway.

According to the transport model for CMN, when it would be operational, the corridor would attract traffic volumes of 50% of the traffic capacity of 2700 (PCU/h)

considering a speed of 50 km/h. Sanex CMN will provide a four-lane street connection to the Ira Node on the north side of the railway, supporting the circulation in both ways.

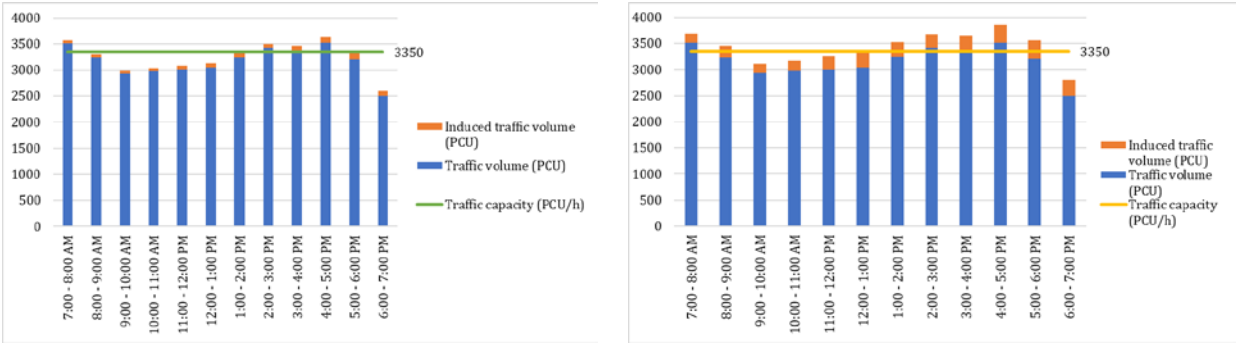
The third step was to develop the traffic model. Induced traffic was distributed in a percentage of 10% on Plevnei Street using the two northern accesses, respectively 90% on the CMN on the two southern accesses. The southern flows were distributed in two variants, according to the stages of CMN completion:

- Variant 1: Complete CMN – half traffic towards the Railway Station Square and the other half towards IRA Node.
- Variant 2: Sanex CMN – all traffic towards IRA Node.

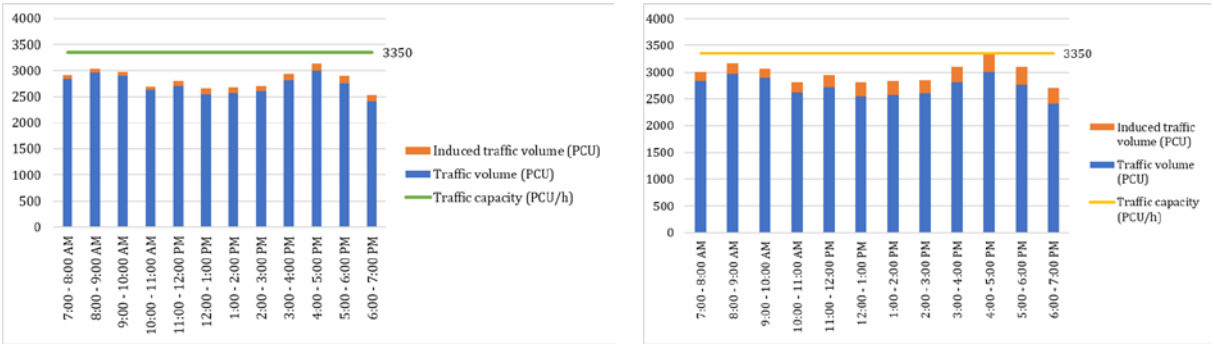
Figure 12. CMN transvers profile [48].

Variant 1 **Variant 2**

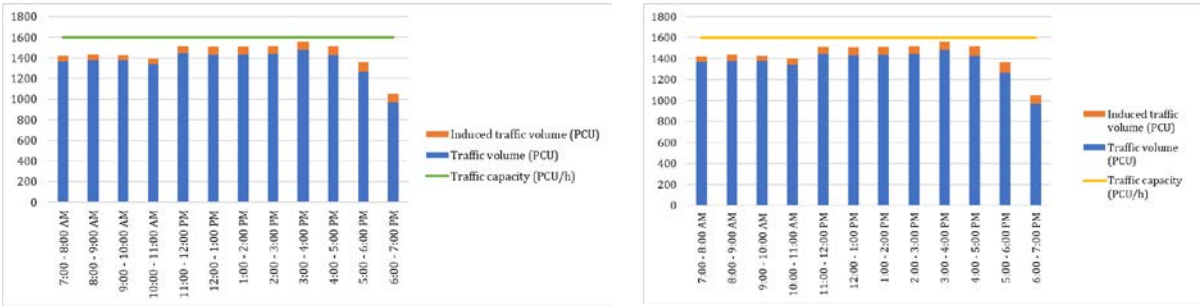
Aurel Vlaicu Street



Traian Vuia Street



Plevnei Street



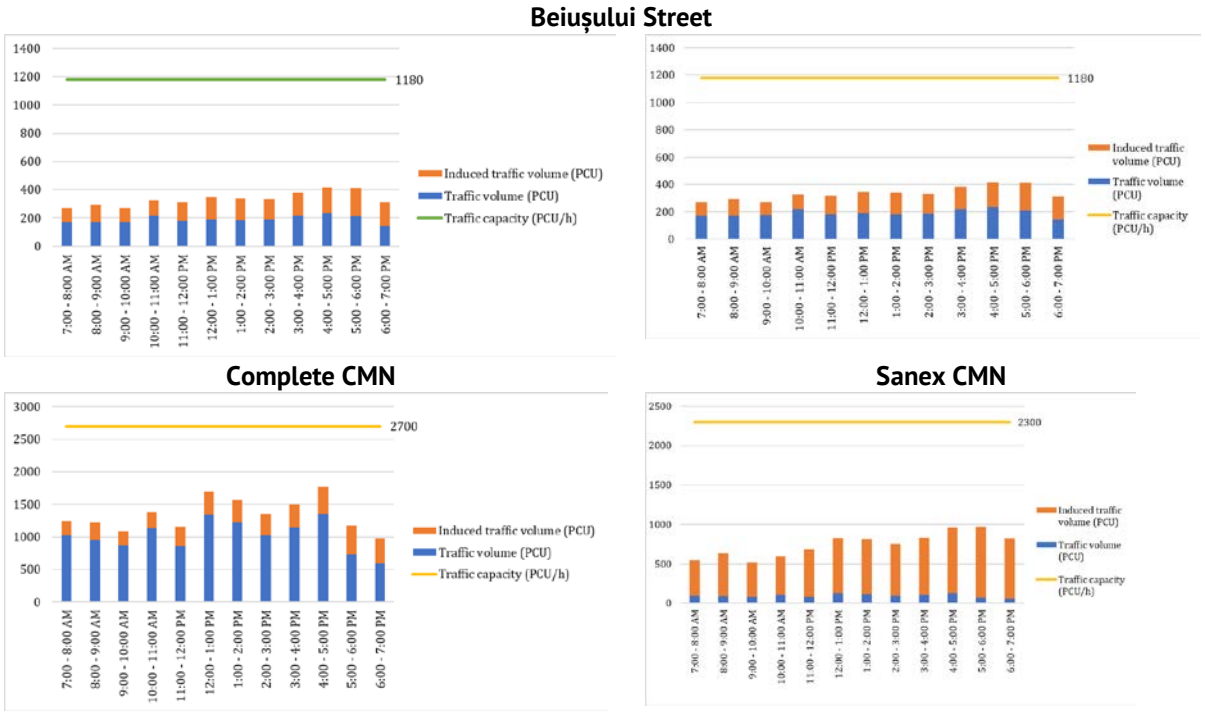


Figure 13. The characteristics of the adjacent street network in the future scenario – the two variants of the model.

The fourth step was to estimate the impact of TOD Sanex development on the local traffic using induced traffic values in the perspective in which the development would be completed (Figure 13).

The traffic capacity was exceeded on Aurel Vlaicu Street by 8% in 4 hourly intervals in Variant 1 and 15% in 7 hourly intervals in Variant 2 (Figure 13). The traffic capacity was not exceeded on Plevnei Street or Traian Vuia Street. The V/C ration does not exceed the limit of 25% in any case (Table 3).

Considering the V/C ration in present and future scenario, the traffic capacity would only be exceeded on Aurel Vlaicu Street, with or without Sanex redevelopment. The impact of the Sanex redevelopment on the local traffic in the case that CMN would be completed, would be 3% increase in V/C ratio.

Table 3

V/C ratio (%)

Street	Scenario 1 - Present	Scenario 2 - TOD Variant 1 Complete CMN	Sanex implementation Variant 2 Sanex CMN
Aurel Vlaicu	105	108	115
Traian Vuia	90	94	99
Plevnei	92	97	97
Beiușului	20	35	35
Câmpul Pâinii	9	-	-
CMN	-	65	24

In case that CMN Sanex wouldn't be implemented, the transport model would be different. Respectively, it was estimated that the induced traffic was distributed in a proportion of 50% in the analyzed network. This would generate exceeding traffic capacity on three links, with a maximum of 19% during eight hourly intervals on Aurel Vlaicu Street,

3% in 1 hourly interval on Traian Vuia Street and a maximum of 18% during eleven hourly intervals on Plevnei Street.

Therefore, the results of this comparative analysis denote that implementing Sanex redevelopment together with Sanex CMN has a major impact both in the development of the area and in the support of the induced / attracted traffic resulting from the implementation of the redevelopment. Furthermore, CMN will be financed partially from private investments and the municipality will also benefit from the public-private partnership.

In the present scenario, two analyzes were carried out for each intersection. Simulations were carried out using Arcady/picady to evaluate the level of service of each intersection and the delays. For accurate modeling of road traffic, the results from the traffic counting were used. The centralized situation for the intersections requested in the study in the current version and the perspective of achieving the objective is presented in the following.

The model of the main intersection, I13, was analyzed in both scenarios – current situation with existing traffic flows (Scenario 1 in Figure 14) as well as in the perspective of the platform redevelopment with additional values of the induced traffic (Scenario 2 in Figure 14).

The induced traffic did not change the exploitation parameters. The results showed that additional values of the induced traffic did not influence the level of service, which remained C but the delays varied from 18 s in Scenario 1 to 19 seconds in Scenario 2.

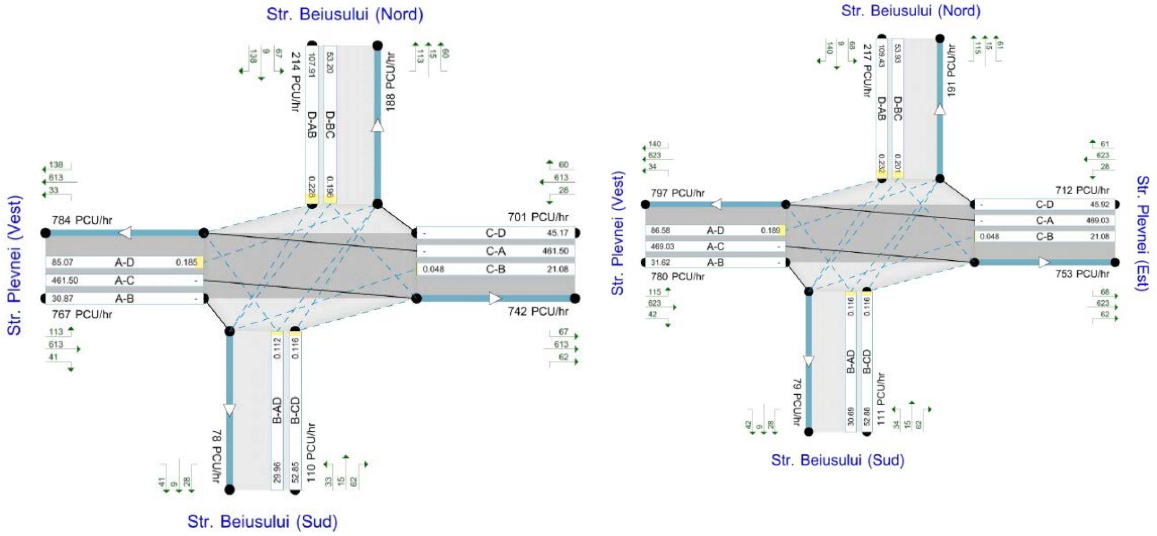
The design of the intersection proved to be correctly chosen. On a medium or long term, it would be possible that intersection I13 would need a reconfiguration taking into account the microscopic modeling of the intersections in the proximity of the development.

The traffic on Beiușului Street represented about 1% of the total traffic in I13.

There were in total 22 intersections that were analyzed since IRA Node was modeled as a suite of 3 intersections. From these, only four intersections changed the level of service, 2 of them from D to E, one from C to D and one from A to B with an increase of 3 seconds delay on average.

Scenario 1

Scenario 2 – with additional value of induced traffic



a)

	AM						
	Queue (PCU)	95% Queue (PCU)	Delay (s)	RFC	LOS	Junction Delay (s)	Junction LOS
	A1 - Scenario 1						
Stream B-CD	0.27	~1	12.37	0.21	B	18.43	C
Stream B-AD	0.33	~1	28.61	0.25	D		
Stream A-B	-	-	-	-	-		
Stream A-C	-	-	-	-	-		
Stream A-D	0.44	1.00	12.74	0.31	B		
Stream D-AB	0.69	1.00	15.93	0.41	C		
Stream D-BC	0.75	2.00	36.43	0.44	E		
Stream C-D	-	-	-	-	-		
Stream C-A	-	-	-	-	-		
Stream C-B	0.09	~1	10.24	0.08	B		

	AM						
	Queue (PCU)	95% Queue (PCU)	Delay (s)	RFC	LOS	Junction Delay (s)	Junction LOS
	A1 - Scenario 1						
Stream B-CD	0.27	~1	12.63	0.22	B	19.17	C
Stream B-AD	0.36	~1	30.07	0.27	D		
Stream A-B	-	-	-	-	-		
Stream A-C	-	-	-	-	-		
Stream A-D	0.45	1.00	12.96	0.31	B		
Stream D-AB	0.73	2.00	16.47	0.42	C		
Stream D-BC	0.81	2.00	38.64	0.46	E		
Stream C-D	-	-	-	-	-		
Stream C-A	-	-	-	-	-		
Stream C-B	0.09	~1	10.33	0.08	B		

b)

Figure 14. Intersection I13 modelling – level of service and delays – two scenarios: a) Intersection model; b) level of service and delays.

5. Conclusions

The redevelopment of the industrial platforms into multifunctional areas including housing, shopping, services, offices, leisure and so on will reduce traffic in connection to the city, shortening the trip lengths and reducing travel times for people. Moreover, it will offer more affordable housing near basic facilities and services.

TOD Sanex will generate additional local traffic volumes of significant values in comparison to the present flows. However, the results of the analyses prove that the induced traffic doesn't have a considerable impact on the conditions of the local traffic in any of the two scenarios - at the present time or in the perspective of the redevelopment. The estimated V/C ratio, level of service and delays in the two scenarios show that induced traffic can be integrated by the current street network, which has different reserve capacity on different links. Thus, the network could operate in appropriate conditions.

Furthermore, the variants of Scenario 2 in which two different stages of completion of CMN are analyzed – Complete CMN against Sanex CMN, denote that implementing Sanex redevelopment together with Sanex CMN has a major impact both in the development of the area and in the support of the induced/attracted traffic resulting from the implementation of the redevelopment. Furthermore, CMN will be financed partially from private investments and the municipality will also benefit from the public-private partnership.

In perspective, traffic is expected to gradually increase in the analyzed area. To counteract this situation, the local authority plans to implement compensatory measures that will restore the V/C ratio within limits. Investments such as the construction of the CMN to increase the capacity of the road infrastructure or implementing suitable public policies to guide the integrated planning of the new developments or redevelopments are just two specific examples in this regard.

The implementation of public projects in the area, such as metro and metropolitan train will lead to an increased use of public transport, as an alternative to car usage. It is necessary to encourage the future residents to use public transport considering the great accessibility to public transport routes and the great connection with other parts of the city.

The findings in this paper could be used to guide the future development in the area, focusing on ensuring a safe and efficient street network in accordance with the urban mobility plan of the municipality. Continuing to integrate TOD principles into urban planning in Cluj-Napoca will lead to better implementation of sustainability in the development of the city.

TOD Sanex is the first documented case study in Romania. Further research should focus on differentiating horizontal and vertical urban densification. Authors need to analyze

several case studies from different urban areas to develop a detailed methodology for implementing TOD.

This article is based on a presentation by the author at the XIth edition of the International Conference 'Current problems in urban planning and architecture', held on 15-17 November 2022 at the Faculty of Urbanism and Architecture, Technical University of Moldova, Chisinau, marking the 50th anniversary of the faculty's foundation.

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THE USE OF VEGETABLE-DERIVED PROTEINS FOR NEW FOOD PRODUCTS

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Abstract. Nowadays there is a high concern with newly-identified protein sources to substitute all kinds of proteins derived from animals. The food industry faces a challenge to produce quality food products that can feed more than nine billion people by 2050, upholding the principles of a sustainable and environmentally affordable way. This idea can be supported by the use of legumes that stand out with appreciable protein content, rich in essential amino acids that increase the foaming and emulsifying properties as well as the dietary fiber content. In recent years, in order to solve environmental and social problems and to diversify food products to cover different nutritional types, proteins of plant origin are used to replace those of animal origin. The present work described a review about emerging alternative proteins for nutrition which focuses on its properties and characteristics.The work analyzes the influence of alternative proteins sources on the food products'sustainability.

Keywords: *plant-based proteins, animal proteins, legumes, aquafaba, meat analogues.*

Rezumat. În zilele noastre există o mare preocupare în ceea ce privește substituirea tipurile de proteine derivate de la animale cu surse de proteine nou-identificate. Industria alimentară se confruntă cu o provocare de a produce produse alimentare de calitate, care să poată hrăni mai mult de nouă miliarde de oameni până în 2050, susținând principiile unui mod durabil și accesibil din punct de vedere ecologic. Această idee poate fi susținută prin utilizarea de leguminoase care se remarcă printr-un conţinut apreciabil de proteine bogate în aminoacizi esențiali cu proprietățile de spumare și emulsionare importante precum și conținutul de fibre alimentare. În ultimii ani, pentru a rezolva problemele legate de mediu, probleme sociale și pentru a diversifica sortimentul de produse alimentare în vederea satisfacerii cerințelor diferitor grupuri de consumatori, proteinele de origine vegetală sunt folosite pentru a le înlocui pe cele de origine animală. Lucrarea de față prezintă o analiză de sinteză despre proteinele alternative emergente specifice industriei alimentare şi influenţa acestora asupra sustenabilității produselor alimentare.

Cuvinte cheie: *proteine vegetale, proteine animale, leguminoase, aquafaba, analogi de carne.*

1. Introduction

The wonder of leguminous crops lies in their capacity to accumulate substantial quantities of proteins and other valuable biologically active organic and inorganic substances in fruits and seeds [1].

On the international stage there is a rich experience in utilizing compounds derived from plant raw materials as additives in food technology to enhance structural and mechanical properties of the end product and improve organoleptic characteristics.The use of natural additives from plant materials not only improves the quality and expands the range of food products but also allows for the rational use of local resources.Therefore, besides their specified technological functions, natural additives from vegetable materials, due to the content of native biologically active substances, augment the biological value of the end product [2].

The use of plant materials with surface-active properties as foaming and emulsifying agents from the composition of natural plant tissues is, primary being natural compounds with a high degree of absorption in the consumer's body [3]. Most of these compounds contain surfactants such as proteins and pectins.

Additionally, a group of compounds containing saponins alongside proteins and pectins is notable. Similar to pectins, saponins reduce blood cholesterol levels, thereby reducing the risk of atherosclerotic vascular lesions, and exhibit anticancer properties [4].

In recent years, due to concerns for health and the environment, there is a rising trend to replace eggs with plant-based ingredients, based on plant proteins [5, 6] or starch [7], which have the same foaming and emulsifying properties as chicken eggs, containing not only proteins and pectins but also saponins. The increasing interest in egg-free products is supported by three main aspects: health, dietary preferences, and economic factors. One of the reasons for excluding eggs from the diet is the presence of phenylketonuria. Phenylketonuria is a disorder of amino acid metabolism that, if untreated, can cause irreversible mental health disability [8]. The diet for treating phenylketonuria is based on avoiding foods with high protein content, such as meat, seafood, eggs, milk, nuts, and related products [9]. Another health-related issue is egg allergy, which is one of the most common food allergies [10], second only to cow's milk protein allergy [11]. Major egg allergens are mainly present in egg whites and can trigger life-threatening symptoms [12]. Concerns also persist regarding the cholesterol content in eggs due to associations between cholesterol and cardiovascular diseases [13]. Another health concern for consumers is so called bird flu, an asymptomatic viral infection, leading to international declines in egg sales [14]. Consequently, bird flu outbreaks have affected not only consumption but also egg production, causing serious financial problems in the global poultry industry [15]. Different food preferences and needs, based on consumer attitudes and beliefs, influence consumption and purchasing power and can lead to the development of new food products [16, 17]. Consumer food choices can also be dictated by religion and certain beliefs that establish dietary rules regarding permitted and prohibited foods [18]. Economic factors associated with egg replacement take into account the high cost, transportation difficulties, and storage of fresh eggs based on the limited distribution of the refrigeration chain [19], and their short shelf life, prompting producers to seek alternatives to eggs.

Egg substitutes can be classified into three main groups:

- Based on concentrated and isolated protein forms.

- Sources of plant-based proteins.
- Additives, namely hydrocolloids and/or emulsifiers.

In recent years, numerous studies have been published on the partial or total replacement of eggs in food products using egg substitutes from various sources. The potential use of bovine plasma [20] as an egg substitute in cake production has been analyzed. Additionally, egg replacement in cake production with whey [21]; legumes, especially soy [22], lentils [23], peas [24], and lupin [25], as well as combinations of hydrocolloids such as xanthan gum, guar gum, carboxymethyl cellulose, hydroxypropyl methylcellulose, carrageenan, and/or arabic gum. Some researchers have evaluated the possibility of using gel from chia or banana seeds [26] as an egg substitute. Furthermore, a growing trend is the use of aquafaba, the cooking water of legumes, especially chickpeas [27], an ingredient with high foaming, emulsifying, and thickening capabilities due to its protein, carbohydrate, and saponin content [28], at an appropriate pH and NaCl concentration [29]. Thus, aquafaba has earned a reputation for transitioning from food waste to a nutritionally and biologically valuable ingredient [30]. In this regard, aquafaba could represent a cost-effective and accessible egg substitute for the production of food products such as ice cream, mayonnaise, and confectionery items. Although aquafaba has been classified as a functional ingredient for confectionery products [31], it has been used by few researchers for cake production [32].

Legumes, due to their elevated protein content, can be used in food as meat substitutes. The method of preparing meat-type products such as sausages, salami, burgers, etc., involves the total or partial replacement of meat with legume flour [33]. However, the acceptance of reduced meat consumption and meat replacement with alternative proteins is still generally low in western countries [34-37]. Consumers need to recognize the importance of adopting plant-based food products to support campaigns advocating reduced meat consumption by animal rights/welfare organizations and address increased greenhouse gas emissions detrimental to the environment caused by livestock farming [38].Perspectives on consumer practices related to the use of plant-based substitutes in obtaining meat analogs are crucial/important, first of all, because nutritional analogs with improved nutritional status and high biological value can be produced. This aligns with the promotion of a healthy lifestyle, the preservation of animal life, and the enhancement of environmental sustainability in the context of a sustainable circular bioeconomy [39].

2. The importance of legumes in human nutrition

Legumes (*Fabaceae*) are angiosperm, dicotyledonous plants, numerous (approximately 10,000 species), and diverse. They originate from tropical and subtropical regions around the globe. Their seeds contain 19.5-40.3% protein, which is 1.5-3 times more than cereals. Plant proteins are accessible nutrients with a favorable impact on consumer health, despite the high demand for animal-origin protein [1]. Food Agricultural Organization (FAO) statistics show that the demand for animal-origin protein-rich food products exceed the supply by four times. The deficit of animal protein can be alleviated only by increasing legume crop production [1] and utilizing them in food production.

Legumes are the second most important group of crops after cereals in human nutrition [40]. This is attributed to their low cultivation cost, nutritional properties, and beneficial physiological effects [2]. The most common edible legumes include beans, peas, chickpeas, lentils, soybeans, peanuts, and lupins. In the Republic of Moldova, the average

production of legumes is around 56 thousand tons annually. The most prevalent crops are beans, constituting about 34% of the total production, peas 19%, chickpeas 13%, and lentils 5% [41].

Legumes are cultivated on a large scale for their nutritional properties, high protein content in seeds, and varied mineral substance content. The mineral content of legumes varies depending on the type and variety of legumes [42]. The regular consumption of legumes reduces individuals' susceptibility to chronic diseases such as cardiovascular diseases, diabetes, cancer, and excess body weight [3]. This may be due to the high content of protein, dietary fiber, essential fatty acids, and isoflavones [2].

3. Chemical composition of legumes

Due to their high nutritional value, legumes are widely used as a primary source of protein, especially in vegan diets. In addition to proteins, legumes are rich in essential components for the human body, such as minerals and vitamins B, and other vital health-protective compounds (phenolics, inositol phosphates, and oligosaccharides). They boast a low glycemic index, making them suitable for individuals with diabetes. Leguminous plants comprise numerous species, with seeds differing significantly in chemical composition and nutritional value, Table 1 [43].

Table 1

Chemical composition of legumes

Legume	Protein content, %	Fat content, %	Carbohydrate content, %	Mineral content, %	Source
Chickpeas	25.1	4.5	63.0	4.7	[1]
Beans	22.3	1.2	72.5	4.0	[44]
Green Peas	22.9	1.5	55.8	3.3	[45]
Lentils	30.4	2.1	54.0	4.2	[46]
Soybeans	32.7	15.7	30.1	3.6	[47]
Lupins	40.8	4.4	41.6	4.3	[48]

Legumes are characterized by a high dry matter content, with significant variation in minerals content among different legume varieties, ranging from 2.5% to 4.4% [44, 49]. They also feature a high protein content, with some varieties such as soy and lupins containing up to 48.2%, while lentils and beans have recorded the lowest protein content at 21.9% [43, 50]. The nutritional role of legumes in the human body is determined not only by their protein content but also by their structure and functions. Two protein fractions, albumins and globulins, are distinguished. Albumins, comprising approximately 10-25% of total proteins, serve structural and enzymatic functions in the human body. Legumes with higher albumin content exhibit increased nutritional value. Globulins, mainly considered immune proteins, constitute about 60-75% of total proteins in peas, soy, and lupins and 80–90% in beans and chickpeas [52]. The fat content of legumes varies from about 1% to 19.4% [43, 49, 50, 53]. Nutritionists emphasize the necessity of legume consumption due to their dietary fiber content, essential for the digestion process [54]. Scientific data indicate significant variation in legume fiber content, ranging from 11.7% to 22.8% [55]. The amino acid profile of legume proteins demonstrates the diversity of amino acids in their composition and the difference in endo- and exogenous amino acid content between species. Peas, chickpeas, and beans exhibit the highest amounts of essential amino acids [56, 57]. Antinutritional substances include compounds that significantly diminish the

nutritional value of legumes, such as chymotrypsin and trypsin inhibitors. These negatively impact protein digestion processes by complexing with proteins and blocking proteolytic enzyme activity [58]. The highest content of these compounds is identified in peas, while lupins and beans exhibit the lowest values [59]. Tannins in legume seeds are classified as antinutritional compounds. Lupins show the highest tannin content, while other legume species analyzed present relatively low tannin levels [60]. Tannins, as polyphenolic compounds, can form stable complexes with proteins, minerals, and vitamins A and B_{12}, resulting in digestibility inhibition. This negative effect of tannins can be mitigated through heat treatment of legumes [61].

Legumes are increasingly recognized as a potential source of antioxidants, containing phenolic compounds with significant antioxidant activity. These compounds are primarily present in the legume seed coat, with colored flower varieties containing higher antioxidant amounts [62]. Chickpeas and beans exhibit the highest values for total phenols, while peas contain approximately 50% fewer phenolic compounds [63-65]. Lentils and lupins show the highest antioxidant activity, beans present average values, and chickpeas and peas have the lowest antioxidant activity [66, 67].

4. Chemical composition and properties of legume boiling water

Legumes are suitable for use in the food industry due to their high nutritional value, relatively low allergy risk, high yield, and low cost [68]. Thus, legumes are considered an adequate protein source as an alternative to animal proteins.

Legumes primarily consist of starch and water-soluble fibres and are rich in polyphenols, carbohydrates, and proteins, with nutritional and structural characteristics varying by variety, Table 2 [69].

Cooking water from legumes, known as aquafaba, has been widely used as a substitute for egg whites due to its excellent functional properties in forming stable foam and emulsion, similar to those of egg whites [74].

Table 2

Chemical composition of aquafaba

Aquafaba	Dry substance content, g/100g	Mineral content, g/100g	Protein content, g/100g	Carbohydrate content, g/100g	Saponine content, mg/g	Source
Chickpeas	5.1	0.6	1.0	3.6	4.5	[70]
Soybeans	5.5	0.8	0.7	4.1	6.4	[71]
Beans	3.3	0.8	0.7	1.8	5.9	[72]
Lentils	4.7	0.5	1.5	2.7	12.0	[72]
Peas	1.8	0.26	0.6	0.7	3.5	[73]

Therefore, it was explored the possibility of using legume boiling water in food manufacturing. It has been demonstrated that the carbohydrates and proteins transferred from legumes to the cooking water during boiling are responsible for the formation of stable foam and emulsion [69]. However, the quality of aquafaba varies depending on the legume variety and the production technology [74, 75]. To ensure the consistency of aquafaba and the quality of products obtained using this ingredient, standardizing aquafaba production is necessary.

This involves selecting specific legume varieties for aquafaba production and determining manufacturing conditions, including the water-to-bean ratio, the use of additives, temperature, pressure, and time [76, 77].

5. Possibilities of using aquafaba in the production of food products

Mayonnaise is a popular semisolid food product that enhances the texture and flavor of dishes such as salads and sandwiches. In recent years, due to health concerns, there has been a growing trend to replace eggs with plant-based ingredients in mayonnaise production [5]. One notable attempt involves creating plant-based mayonnaise using aquafaba from chickpeas [78]. Aquafaba was obtained from Kabuli chickpeas, known for its high emulsifying properties [75]. The process to obtain liquid aquafaba involved soaking chickpeas in water at 4 ºC for 16 hours, followed by boiling for 30 minutes. Ingredients like rapeseed oil, chicken eggs, table salt, vinegar, and crystalline sugar were used. In the production of vegan mayonnaise was utilized dried aquafaba. The most effective drying method for aquafaba, which preserved its high emulsification properties, was identified. Five different drying methods were employed: freeze-drying, spray drying, convection oven drying, rotary evaporator drying, and vacuum drying. The powdered form of aquafaba, dried in a convection oven at a temperature of 80 °C until a constant mass was achieved, was used in the preparation of vegan mayonnaise [79, 77].

The stability of the mayonnaise was assessed by studying the microstructure and particle size distribution. The vegan mayonnaise remained stable during storage, maintaining a consistency identical to mayonnaise prepared with eggs. The sample of vegan mayonnaise exhibited good stability upon heating, on the first day, the 14th day, the 21st day, with peak values on the 28th day compared to egg mayonnaise. It is noted that chickpea aquafaba obtained by boiling contains heat-stable proteins [76], which could contribute to the stability of vegan mayonnaise during heating. The sample of vegan mayonnaise had a less acidic environment (pH ranging from 3.74 to 4.66) compared to egg yolk mayonnaise (pH=3.24 to 3.96). Color parameter values showed a distinct difference between egg mayonnaise and vegan mayonnaise, with the latter having a darker appearance and lower color intensity [77]. Previous research has indicated that the emulsion color can shift from gray to increasingly bright white as droplet size decreases, likely due to increased light scattering [80, 81].

In the production of Macaron-type biscuits, chickpea aquafaba and flaxseed gel were used as plant-based foaming agents [82]. The quality of the formed foam and the volume of the dough obtained after beating were analyzed. The dough volume of aquafaba biscuits was similar to the control sample, while the dough obtained from flaxseed gel resulted in a 40% reduction in volume compared to the control sample. Additionally, the height of the semifinished product for aquafaba-based biscuits was similar to the control sample, while the flaxseed gel biscuits had significantly lower height. Texture parameters and organoleptic characteristics for aquafaba biscuits showed high values close to the control results [83].

In the category of products that include brioche, spray-dried legume aquafaba was used as a foaming agent [22, 84-87]. The specific volume of these brioche was lower compared to egg-based muffins [88], but the results regarding the mass loss during baking showed much lower values for aquafaba muffins compared to the control sample. The parameter, mass loss, is closely related to the hydration capacity of legume aquafaba powder [89]. Therefore, mass loss during baking is low when the hydration capacity is high.

For the color parameters CIELab (L*, a*, b*) of the muffins, the best results were obtained for those with eggs. Significant differences were observed between the values of the crumb and crust; the carbohydrate components present on the product's surface lightly brown through heating [90]. This could be attributed to the Maillard reaction that occurs during baking [91]. The textural characteristics of the muffin samples evaluated (hardness, adhesiveness, cohesiveness, elasticity, gumminess, and chewiness) did not show significantly different results. According to a previous study [88], firmness, gumminess, and chewiness depend on the hygroscopicity of the product, by affecting the state of starch when subjected to the processes of gelatinization or retrogradation [23, 92]. The results of the sensory analysis did not show significant differences between characteristics for all samples. It was found that the evaluated attributes were closely related to each other. Overall acceptability was primarily influenced by aroma, followed by appearance, uniformity, and the volume of the muffin [93].

6. The use of legumes as meat analogues

Approximately one third of all global greenhouse gas emissions (GHG) are attributed to the food production system. Cattle breeding generates 7% of it [94]. This goes against the objectives of a circular bioeconomy, especially since beef production can have GHG emissions of almost 20 times that of tofu, or more than 100 times that of nuts [95]. On the other hand, based on the data presented by FAO (2020) meat is a good source of proteins but frequently is considered not efficient regarding use of resources, mainly passing the harvest calories to meat calories, utilization of 80% of cultivable areas and 70% of fresh water [96].

Another aspect is the health problems associated with eating meat while meat substitutes are sources of plant-based protein that are cholesterol-free and low in saturated fat and contain essential amino acids beneficial for health [4].

Legumes can also be used in the formulation and production of meat analogues, which are rich in protein, starch, fiber and essential amino acids (arginine, lysine, glutamic acid, leucine and aspartic acid) [97, 98]. Legume proteins are recommended in the production of these products due to their foaming and gelling properties, but they have a lower digestibility compared to proteins of animal origin, Figure 1 [99].

Firstly, because of structural differences between these two kind of proteins. Plant based proteins are rich in β-sheet structures and poor in α-helixes in comparation with animal proteins. Such structure negatively influenced the digestion process. Secondly, legumes have a large amount of fibres, a feature that slows down the digestion process. The quantity of antinutritive factors of plant-based proteins, is an other element that affect the digestion [101].

However, there are methods for improving the properties that slow down the digestion of these proteins. On the one hand to adjust the protein digestibility-corrected amino acid score to the value of 1, thus approaching the value of this index for animal proteins. On the other hand, to balance the anabolic response of plant-based proteins as the consumed amount increases. An other way to increase the quality indices of plant based proteins is the fortification with amino acids. Good results were obtained after blending diferent sources of plant proteins, producing a complex source of amino acids [102] as in case of rise and pea that could increase the PDCASS indices to 1.00 [103].

Soy, for example, is a readily available and widely used ingredient in meat analogues around the world. Soy is famous for its excellent nutritional and functional attributes, it is

rich in carbohydrates, fats, fibers, vitamins, micro and macronutrients [104]. Due to the proportional nutrient content of soy, it can be used to replace red meat [105]. Because its proteins have the ability to reduce blood cholesterol, they are indicated in the manufacture of meat analogs intended for consumers suffering from cardiovascular diseases [106]. In the development of this branch of the food industry, obtaining sausages and similar products, nuggets, soy proteins can be used in both untextured and textured form [107, 108].

Defatted soybean meal is used to obtain textured vegetable proteins by stripping soluble carbohydrates and texturing the filtrate by spinning or extrusion [109].

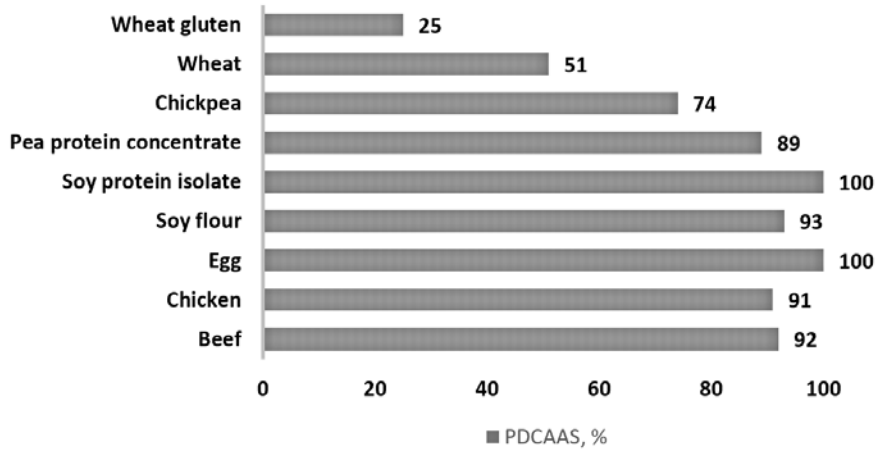

Figure 1. Protein digestibility-corrected amino acid score (PDCAAS), adopted from [100]**.**

Textured soy protein concentrates mimic meat muscle fibers (turkey or chicken breast meat fibers), provide meat analog fibrous characteristics, such as chewiness, firmness [110]. Peas protein meat analogues have a fibrous texture similar to that of fish and chicken meat, which contained 90% protein from pea protein isolates, gluten and high moisture starch to improve the product's moisturizing properties [111].

7. Conclusion

Currently there is a great preoccupation regarding the substitution of proteins of animal origin with vegetable protein sources. The fruits and seeds of legumes contain important amounts of proteins and biologically active substances, as well as other compounds. Plant-based proteins have a favorable impact on the health of consumers. The animal protein deficit can only be alleviated by increasing the production of legumes and their use in food production. In the Republic of Moldova, the most widespread crops are beans, followed by peas, chickpeas, and lentils. Legumes are suitable for use in the food industry due to their high nutritional value, relatively low allergy risk, high yield, and low cost.

Aquafaba is a by-product of the preservation or boiling processes of legumes. It can be widely used as a substitute for egg white due to its excellent functional properties of forming foams and stable emulsions, similar to those of egg whites. Possibilities of using aquafaba in the manufacture of food (mayonnaise, macaron biscuits, etc.) were analysed.

It has been shown that legumes can be used in the formulation and production of meat analogues. Proteins from legumes are recommended in the production of these products due to their foaming and gelling properties, but they have a lower digestibility compared to proteins of animal origin. Thus, to solve the problems related to the environment, social problems and to diversify the assortment of food products in order to satisfy the requirements of different groups of consumers, proteins of plant origin can be used to replace those of animal origin.

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WAYS OF APPLICATION OF THE CIRCULAR BIOECONOMY IN THE WINE INDUSTRY

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Abstract. The article reviews the conventional (composting, landspreading, tartaric acid, and grapeseed oil production) and novel ways of winemaking by-products biomass conversion with the manufacturing of value-added products to solve the disposal problem and bring extra profit to producers. Winemaking waste may be used to make biopolymers - bacterial polymers that work as a plastic alternative, and can also be utilized to make biocomposites or serve as natural fillers. It showed to be a good substrate for microorganisms for the generation of biofuels from winery waste and is the most promising, economical, and ecologically friendly option. In biotechnological applications, it can be used for the production of microbial polysaccharides, alcohols, organic acids, and enzymes, as well as single-cell protein and protein-rich fungi. The available studies indicate that it is possible to create pharmaceuticals with multiple properties of preventing or treating obesity and multiple sclerosis, atherosclerosis, diabetes, allergies, and also benefit gut microbiota. The red grape marc can be used in manufacturing encapsulated natural pigments, applicable for baked products, dairy, soft drinks, and pasta making it a feasible alternative to synthetic colorants. Considering the available opportunities, it is advised the development of industrial technologies and quality standards for the available studies introduction.

Keywords: *winemaking by-products, extracts, sustainable development, waste recycling, circular approach.*

Rezumat. Articolul trece în revistă modalitățile convenționale de conversie a biomasei din subproduse de vinificație cu fabricarea de produse cu valoare adăugată pentru a rezolva problema eliminării gazului de seră și a aduce profit suplimentar producătorilor. Subprodusele de vinificație pot fi folosite pentru a obține biopolimeri - polimeri bacterieni care funcționează ca alternativă a plasticului și pot servi drept materiale de umplutură naturale. Tescovina prezintă un substrat bun pentru microorganisme în vederea generării de biocombustibili din deșeurile de vinărie și este cea mai promițătoare, economică și ecologică opțiune. În aplicații biotehnologice, tescovina de struguri poate fi utilizată pentru producerea de polizaharide, alcooli, acizi organici și enzime, precum și proteine unicelulare și ciuperci bogate în proteine. Studiile disponibile indică faptul că este posibil să se obțină

produse farmaceutice cu proprietăți multiple de prevenire sau tratare a obezității și sclerozei multiple, arteriosclerozei, diabetului, alergiilor și pentru microbiota intestinală. Tescovina de struguri roșii poate fi folosită în fabricarea pigmenților naturali încapsulați, aplicabili pentru produse de copt, lactate, băuturi răcoritoare și paste, fiind o alternativă fezabilă pentru coloranții sintetici. Având în vedere oportunitățile disponibile, se recomandă dezvoltarea tehnologiilor industriale și a standardelor de calitate pentru implementarea studiilor disponibile.

Cuvinte cheie: *subproduse de vinificație, extracte, dezvoltare durabilă, reciclare a deșeurilor, abordare circulară.*

1. Introduction

Nowadays, in the Republic of Moldova it is manufactured about 14 mln dal of wine yearly [1]. Winemaking is a secularly-rooted economic activity in the Republic of Moldova that contributes 9% of the country's gross domestic product, making it one of the most significant sectors of the economy there. Wine production is a very sophisticated and costly technological process, as only 70% of the raw material is used to make this product, with the other 30% resulting as waste (around 100 000 to 200 000 t each year) [2]. Inappropriate handling of these materials may cause both ecological and food safety problems. Recycling is one of the viable solutions to solve this problem and avoid waste accumulation. Winemaking by-products have a high potential as raw material for various value-added products, including fertilizers, biopolymers, pharmaceuticals, functional foods, etc. This article reviews various possibilities of winemaking by-products treatment methods and valorification options, in terms of industry evolvement towards more sustainable approaches and circular bioeconomy principles application.

According to Law no. 57 on Vine and Wine of the Republic of Moldova, waste resulting from the production of wines and processing of secondary products of winemaking is subject to mandatory processing only at permitted enterprises in accordance with the requirements for environmental protection, transfer of waste to specialized enterprises for energy conservation and processing of industrial waste, as well as requirements for waste storage, not subject to processing, at specially equipped landfills [3]. Categories of secondary products of winemaking, provided by the current legislation of the Republic of Moldova are grape pomace, wine stillage, yeast stillage, diffusion juice, piquette, wine stone, stem must, and wine yeast. From mentioned by-products on the territory of the Republic of Moldova, it is legal to produce such categories of value-added products as enocolorant (a natural food coloring obtained from strongly colored red grapes), enotanine (a product obtained by the extraction of phenolic substances from grape seeds), calcium tartrate (sediment obtained from secondary products of winemaking, containing salts of tartaric acid), grape seed oil [4].

2. Basic principles of the circular bioeconomy

The word "sustainability" was adopted to close the gap between development and the environment. Sustainable development is defined as development that "meets the demands of the present without compromising the ability of future generations to satisfy their own needs" in the World Commission on Environment and Development's 1987 report [5]. Sustainability is also associated with enhancing long-term prosperity and well-being. Three strategies exist for sustainable development: ecological (preservation of the

robustness and resilience of biological and physical systems), economic (maximization of income while maintaining a constant or rising stock of capital), social-cultural (preservation of the stability of social and cultural systems) [6].

The growing scarcity of resources used in agriculture, such as water, is projected to impede the expansion of agricultural output. Greater agricultural productivity came at a significant environmental cost and the expense of some non-renewable agricultural resources. The developing world is now where the environmental consequences of agricultural development are most noticeable. This may be seen, for instance, in the nations' increasing per-hectare use of synthetic fertilizers and pesticides. The beginning of climate change is another significant obstacle to the sustainability of agricultural production [7]. Climate change, environmental degradation, and biodiversity loss have driven Europe to transition from a fossil-based and linear economy to a bio-based circular economy model. The bioeconomy is the production of renewable biological resources and the conversion of waste streams into value-added products [8].

Biowaste is defined by the European Commission as "biodegradable garden and park waste, food and kitchen trash from residences, offices, restaurants, wholesale, canteens, caterers, and retail locations, as well as equivalent waste from food processing plants". Unmanaged biowaste endangers public and environmental health. Furthermore, when biowaste is disposed of in an unmanaged manner, it contributes significantly to methane emissions, which contribute to climate change [9].

Agriculture, forestry, fishing, food, pulp, and paper manufacturing, as well as portions of the chemical, biotechnological, and energy industries, are all included. Its sectors have a high potential for innovation because they use a diverse set of sciences, enabling industrial technologies and local and tacit knowledge [10].

The circular approach causes three times less environmental impact than the linear system for global warming, freshwater eutrophication and mineral resource depletion [11].

The fundamental obstacles to the implementation of the concept of sustainable development consist in the awareness of the phenomenon of global warming, the lack of financial resources and advanced technologies, as well as the diversity of political and economic objectives on a global and local scale. [12]. Food by-products and waste valorization techniques have lately come to light as methods of sustainable management that may also boost local economies' revenues. To achieve the goal of a zero-waste society, stakeholders need to be more aware of the technologies for by-product recovery produced by academic institutions and research centers as part of the transition to a circular economy [13].

2.1 Combating food waste from production to consumption

Food loss (food spoilage) is defined as "the unintended reduction in edible food quantity or quality before consumption, which includes postharvest losses" [13]. It refers to a decrease in the mass of food that was originally meant for human consumption at all stages of a food chain before the consumer level. Food loss is the least desirable scenario among the others because there is no other option than to reject it.

Food waste is defined as "food that was created for human consumption but was discarded or was not consumed by people, including still edible food that is discarded on purpose" [14]. Food waste is less harmful to the environment than food loss. Depending on the type of food waste, it becomes the raw material for a biorefinery, which can provide material recycling, animal feed, nutrient recovery, or energy recovery.

Surplus food is edible food that has been produced, retailed, or served but has not been consumed by humans. It is the least harmful of all because it is easy to avoid and the surplus produced is still good for human use [14,15].

Differences in food waste between areas and countries are determined, in general, by economic, organizational, and behavioral conditions, and, in particular, by the number of resources in the region and regional behavioral patterns. In some regions, household food waste can be prevented up to 34% [16].

In the food chain there are multiple factors that contribute to the generation of food waste. In the case of agricultural enterprises, these are non-compliant products, resulting from their sorting due to rigorous quality standards regarding mass, size, appearance and shape; prices, which do not always justify the expenses; overproduction due to failure to fulfill supply agreements with retail chains and damage to the crop during harvest. In the manufacturing stage there are such factors as products of irregular sizes, inconsistency of manufacturing processes, contamination in the manufacturing process, food spoilage due to packaging problems, surplus production of supermarket own brands, and canceled commands.

The following factors contribute to food waste during product distribution: a lack of cold storage, packaging defects, overstocking, the requirement for retailers to order a diverse range of products and brands from the same producer, failure to comply with minimum food safety standards, and marketing strategies [17]. In general, a large amount of food waste is generated before the households, and this occurs as a result of a lack of communication and collaboration among food chain members, policies requiring manufacturers to discard non-compliant products, and poor management of all stages of food production and distribution [18].

The following aspects that are required for a successful corporate social entrepreneurship initiative aimed at reducing food waste: clear articulation of the problem and solution; mobilization of civil society actors; continuous investment; and alignment of the initiative's scaling-up strategy with the retailer's resources [19]. Simple things like making lists before going grocery shopping and buying less food can help you reduce your carbon footprint. At this point, money can be saved by purchasing only what is required and avoiding disposal fees. Food waste should be addressed not just through the use of existing and new technologies, but also through education and raising awareness [20]. In theory, the potential for preventing needless food waste is infinite. Apart from physical human requirements, various additional reasons impact consumer behavior, such as self-affirmation and the intrinsic value of buying in itself. Unexpected circumstances, such as storage failure, mite infections, and so on, will also put the theoretical potential to the test. However, the rationale for discarding avoidable food waste is immaterial from an environmental standpoint, as the zero-burden assumption is never applied to avoidable food waste [21]. In different member countries, there were elaborated different prevention initiatives, such as informing the population on food waste reduction in different ways (guidance on food labels, food storage tips printed on carrier bags, revised marketing for promoting perishable goods) or encouraging the retailers to donate the surplus food (exclude the VAT and deduct a part of the donated amount from the taxable income) [15]. Food waste awareness campaigns may have a positive impact on consumer efforts to reduce the amount of wasted food [22]. Environmental awareness is relatively high in industrialized countries, and recycling efforts are commonplace. However, in a developing

country, the urgency of trying to safeguard the environment is still regarded as a low priority due to the belief that "we still have plenty of land" [20].

According to the legal analysis, existing legislation lacks the guiding impact needed to dramatically minimize food waste [23]. On the other hand, adopting new regulations and policies was viewed as ineffective, although no consensus was established among the various types of stakeholders [24].

Under a set of market assumptions, the home food waste reduction might lead to a rise in home savings, a decrease in agri-food production, and a slight negative macroeconomic impact [25]. Some attempts to decrease food waste include collecting undamaged healthy food and distributing it to neighbors or those in need [20]. Italy recently modified its food waste policy by instituting novel measures such as the ability to donate food after the best-before date (BBD) and a major reduction in donation bureaucracy. Food waste experts advocate for these procedures, which are considered to increase donations practically automatically. Furthermore, despite legal measures encouraging food donation, the analysis finds substantial reputational hazards that limit both the supply and demand for food beyond the BBD [26]. Also, anyone, with proper and safe treatment, can contribute food scraps to animals. Farmers have been doing this for a long time, and there are several options to feed these animals. This approach preserves the environment, saves money on disposal fees, and is already prevalent in rural regions [20]. Food waste recycling in animal nutrition may help to reduce the environmental effect and improve the environmental footprint of livestock production [27].

In the US Environmental Protection Agency's (EPA) food recovery hierarchy, landfilling and incineration are regarded as the least recommended and last-resort methods. Incineration technology provides energy by burning garbage; this procedure is not only costly, but it also pollutes the environment due to the chemical emissions it emits. However, landfilling is the most typical waste management solution [20].

The most desirable strategic goal is to manage food waste across the supply chain. Each link in the food value chain can help to reduce or even prevent food waste. To address this issue, supply chain solutions aimed at reducing food waste must be implemented through the integration and synchronization of activities by all involved parties and stakeholders [28]. Systemic waste creation processes are essential to preventing food waste. They must target the identified system processes that contribute to the blockage of the food chain. Transparent monitoring and disclosure of surplus food is necessary to prevent systemic food waste throughout the supply chain [29]. Based on the treatment of a functional unit of 1 ton of food waste, the results show that the bioconversion scenario is the most preferable solution, incineration and bioconversion scenarios exhibit the greatest environmental advantages [30].

2.2 Creating added value with bio-waste and co-products

The recovery of food waste opens up new economic opportunities by using garbage as fuel for bioprocesses. Advanced technologies such as microwave-assisted extraction, ultrasound-assisted extraction, bioreactors, and enzyme immobilization-assisted extraction, as well as their combination, contribute to food waste processing [31].

Biorefining is the use of biotechnology to convert various types of biomass into marketable goods and energy. Currently, the majority of existing biofuels and biochemicals are generated in single production chains. Advanced biorefineries are being designed to

process a broader range of biological resources into a variety of platform chemicals that may then be processed into biocomposites, bioplastics, energy, or food [9].

2.2.1 Biobased polymers

Biopolymers are bacterial polymers that are built as natural storage polyester by a diverse range of microbes, typically in unstructured growth conditions. Carbon source contributes around 70–80 % of the raw material cost as a substrate for both microorganism growth and biopolymer synthesis. This has influenced the manufacture and use of biopolymer because the technique is economically unfavorable overall. As a result, it is critical to minimize the cost of biopolymer manufacturing by utilizing less expensive carbon and nutrient sources [31]. Biopolymers that are derived from raw biomass may occasionally be made directly, but they may also be employed to create biocomposites by being reinforced, acting as natural fillers, or even both. They are frequently used as a bacterial fermentation substrate to produce natural polyesters like polylactic acid and polyhydroxyalkanoate [32].

Pseudomonas bacteria may produce *mcl*-polyhydroxyalkanoates from grape pomaces when used in combination with waste frying oil (*Pseudomonas putida* KT2440 and *Pseudomonas resinovorans*). For the Solaris grape, the production of *mcl*-polyhydroxyalkanoates was 21.3 g/L [33].

Utilizing the strain *Cupriavidus necator* DSM 7237, poly 3-hydroxybutyric acid can be produced in batch and fed-batch fermentation using wine lees and crude glycerol as carbon and nutrient sources. About 30.1 g/L of yield has been produced [33].

Investigated were the wine lees and seed extracts combined with polyhydroxybutyrate. The resulting eco-friendly and affordable biocomposites can be employed in large-scale disposable applications when simultaneous requirements for heat resistance and quick biodegradability are significant. Another study suggested making disposable cutlery out of three different flours (grape, millet, and wheat) combined with xanthan and palm oil as potential alternatives to plastic materials [34].

Grape pomace is known to be used as a substitute for chemical preservatives and natural antioxidants in edible wrapping to preserve the organoleptic properties and increase the shelf life of food products such as burgers and pork, as well as edible films [35].

Red grape seed extract, chitosan, gelatin, and *Ziziphora clinopodioides* essential oil can be used to create a biodegradable edible film with enhanced antioxidant, antibacterial, and phenolic content, as well as improved optical and water barrier qualities [35].

The effect of grape seed extract mixed into chitosan film on extended shelf life for vacuum-packed food under refrigerated settings was studied by taking into account its physicomechanical characteristics, antioxidant, and antibacterial activities. Films were more effective than chitosan films alone at inhibiting certain types of pathogenic microorganisms [36].

Extracted grape skins were demonstrated to be a promising raw material for the manufacture of low-density boards for insulation purposes. Over a wide temperature range, the boards made from grape skins and bound with 8% urea-formaldehyde resin had reasonable tensile strength and moderate thermal conductivity [37].

2.2.2 Biofuels

The production of biofuels from food waste is the most promising, cost-effective and ecological alternative to sustainable development and a circular bioeconomy. Food waste has been described as a substrate for biofuel synthesis. Food waste provides

microorganisms with a complex of nutritious organic components to produce a variety of biofuels.

Hydrochar is a promising alternative to solid fuels. Technological parameters have a significant effect on the final quality of hydrochar. Increasing the processing temperature up to 260 °C resulted in an increased removal rate of N, S, and Cl, and combustion of hydrochar resulted in a significant reduction in NO, SO_2, and HCl emission [31].

2.2.3 Biogas

A possible method for generating energy from alternative renewable sources is the creation of biogas from leftover agro-food biomasses produced through anaerobic digestion. The use of advanced anaerobic digestion plant technologies, such as the combination of anaerobic membrane technology with particular systems, is currently the most promising factor to take into account to improve the anaerobic digestion process for the production of biogas. Additionally, real-time process monitoring should be carried out to regulate the primary process variables and enable effective biogas generation.

The following factors should be considered in future efforts to increase biogas generation from the anaerobic digestion of agro-food waste. A better and more precise characterization is required to mix agro-food waste in the right proportion to increase biogas production and process stability because of the variety in the origin and content of agro-food waste, which gives it special features. Small farms tend to be located in locations with seasonal availability of agro-food waste, which might lead to input unpredictability. This problem can be resolved through collaboration among farms producing various products [38,39].

2.2.4 Bioactive compounds

Bioactive chemicals are health-promoting elements found in small amounts in fruits, vegetables, cereals, and animal sources that provide extra-nutritious and health advantages in addition to the fundamental nutritional value of the meal. As medicinal medications, bioactive substances have antioxidant, cardioprotective, anti-inflammatory, anti-cancerous, immunomodulatory, and antimicrobial activities.

Nutraceuticals have numerous therapeutic benefits with no significant evidence of negative effects. The skin of grapes is left unused and is produced in mass as a by-product from vineyards. It is high in resveratrol (3,5,4′-trihydroxystilbene). Resveratrol is a multifaceted antioxidant that improves the anti-inflammatory response of NF-cells to reduce inflammatory responses, free radical scavenging action, and cytochromes P-450 enzyme activity, which aids in hepatic detoxification [31]. Some nutraceuticals can be utilized to supplement important nutrients for co-adjuvant cancer treatment (breast, lung, and pancreatic) [8].

Nutraceuticals, or functional compounds, have been recovered via membrane methods from novel sources, specifically agro-food by-products. Specific phenolic compounds may be recovered, separated, and fractionated using techniques like ultrafiltration and nanofiltration. These compounds, depending on their biological activity, may find value in the food and pharmaceutical sectors. These separation techniques are also more cost-effective than conventional ones, both in terms of recovery and because they don't call for the use of destructive reagents or added agents. Therefore, the recovery of high-value solutes from agro-food wastes is both ecologically conscientious and industrially viable [40].

The pulsed electric field (PEF) pre-treatment has a significant impact on recovering grape polyphenols. PEF was therefore determined to be the best non-thermal method for extracting certain bioactive chemicals from grape residues. It has been observed that increasing pulse width increased polyphenol yield with higher energy efficiency. Published studies claim that there is a rise in anthocyanin recovery of between 22 to 200 % as compared to the ultrasound and high-voltage electric discharge methods. Also, pre-treatment with PEF is more advantageous for recovery with low turbidity of the extract. As a result, the treated juice wouldn't need to be filtered with harmful filter aids such as diatomite [41,42].

2.2.5 Separation and drying of grape seeds

The seed oil content (recalculated on dry matter) varies from 9.5% to 20.0% depending on the grape variety and the place of cultivation. Approximately 190 - 512 t of grape seed oil can be generated annually. The efficient management of agro-industrial waste can be ensured by modernizing existing technological processes and by developing new processing methods based on high efficiency. The long duration of heat treatment of seeds leads to a decrease in the quality of the oil [43].

2.2.6 Landspreading the grape pomace

It has been established that the vine shoots produced during pruning include phenolic, volatile, and mineral components that are used as foliar fertilizer and a biostimulant for the grapevine [44].

The grapevine draws huge amounts of nutrients from the soil each year and persists in the same location for many years (30-40 and even more). Within a year, the vine absorbs 100-150 kg/ha of nitrogen, 20-50 kg/ha of phosphorus, and 75-250 kg/ha of potassium from the soil. In addition to nitrogen, phosphorus, and potassium, the vine requires the following mineral nutrients on an annual basis: calcium, magnesium, iron, boron, manganese, copper, zinc, molybdenum etc. It is suggested that grape pomace be used as a fertilizer to replenish the soil with nutrients.

Fertilization with fresh pomace - spreading in a thin layer directly on the soil after the grapes have been harvested. Fresh pomace should only be used sparingly and in small quantities in viticulture to avoid erosion.

Composted grape marc fertilization - most composting is done in piles, and the compost is used in the platform after composting. The advantage is that the compost has already been adequately matured by the time it is applied. As a result, the soil structure will increase (pore volume, water retention capacity, aeration, and heating), and nutrients will be more broadly available to plants [43].

The addition of composts made from agro-food sources to vineyard soil boosted the soil's salinity, nitrogen and oxidizable organic carbon contents, and biological activity. Similar to the treatment using compost pellets made from sheep manure, the waste-based compost treatments considerably boosted grape production when compared to the control treatment [45]. Vermicomposting is a viable solution for managing winery waste [46].

2.2.7 Tartaric acid

Tartaric acid is a well-known organic acid found within many fruits, most notably grapes. The most frequent form of acid found in nature is L(+)-tartaric acid, while D(-)-tartaric acid sources are scarce [47]. L(+)-tartaric acid is historically produced as a solid by-

product of wine fermentation, and this method is significantly influenced by the grape development stage and climatic circumstances. Chemical production of L(+)-tartaric acid using maleic acid is also possible, but this produces a substantially less soluble racemic product (DL-form) that is unsuitable for inclusion in foods due to the presence of D(-)-tartaric acid, which is harmful to human health. The chemical process's commercialization is hampered by both the product form and the high production cost. Microbial approaches are currently believed to be substantially simpler and more cost-effective for the production of L(+)-tartaric acid and D(-)-tartaric acid [47]. L(+)-tartaric acid is used in the culinary, wine, pharmaceutical, chemical, and polyester industries. D(-)-tartaric acid is also vital in the pharmaceutical business. Both are well-known chiral chemical building blocks with several industrial and scientific applications [47]. Tartaric acid is preferred in dishes containing cranberries or grapes, such as wines, jellies, and confectioneries [48].

Tartaric acid esters/ethers were evaluated as polyvinyl chloride plasticizers. These compounds have good plasticizing action, a low migration potential, and have no effect on the thermal stability of the polymers [49]. Chitosan and tartaric acid were employed to form the stable double chelating network in magnesium oxychloride cement [50].

2.2.8 Obtaining sorbents from winemaking waste

The transformation of grape pomace into sorbents capable of reducing the concentration of heavy metals in wastewater is a new approach to the processing of agri-food waste. There is also the possibility of producing activated carbon or biochar. Microporous activated carbon obtained from winery waste had a higher capacity to adsorb Mn(VII) than other commercial adsorbents [51] and could be used to successfully remove Pb^{2+} from polluted water [52]. Biochar is less expensive to obtain than activated carbon and has a comparable adsorption capacity [43]. Biochar has the potential to be exploited as a source of bioenergy [53].

3. Wine enterprises - the production structure and possibilities for capitalization of by-products and waste

Wine production is one of the world's most important agricultural enterprises. Wine production necessitates the use of numerous valuable resources, including water, fertilizers, and other organic items. The precise vinification techniques alter the physicochemical qualities of the residual material formed, whose features define its further usage and even condition the subsequent specialized recovery circuit in which it might be integrated. The growing amount of lignocellulosic products generated by the development of agro-industrial activities over the last 100 years has been one of the key environmental challenges in producing countries. To contribute to a healthy environment, wastes are recycled mechanically, chemically, or biologically and repurposed as raw materials for new products and applications. It is the so-called circular economy, which seeks to achieve a "zero waste" society. Vine cultivation and winemaking in cellars generate a large amount of trash and by-products, with only a small portion of these materials being reutilized. Furthermore, wine by-products can be used to value functional components or bioactive phytochemicals for the production of medicinal, culinary, and cosmetic constituents [54].

Grapes are one of the most valuable traditional fruits in the world. It can be eaten raw or used to make wine, juice, jam, jelly, raisins, vinegar, and seed oil. According to the entire grape harvest, around 75% of the grapes have been used for wine production. Wine consumption has increased over time, and the concurrent increase in grape pomace output

has drawn attention. The primary organic solid waste created by the winery business is grape pomace. It is produced in vast numbers throughout the world as a by-product of the processing and fermentation processes. Grape pomace is mostly made up of seeds and skin [35]. Several investigations have demonstrated the potential to recover phenolic and antioxidant fibers from the skin, as well as seed oil. Grape pomace is high in cellulose, lignin, hemicellulose, phenolic compounds and tannins [35].

3.1 Characteristic of wine by-products

Winemaking produces a variety of residues that are rich in biodegradable chemicals. Although winemaking is considered an environmentally friendly operation, between 1.3 and 1.5 kg of waste is generated for every liter of wine produced [36].

Winery and distillery waste has a low pH (3.8-6.8), electrical conductivity (1.62-6.15 Ds/m), and a high organic matter concentration (669-920 g/L). They contain a high concentration of macronutrients, particularly potassium (11.9-72.8 g/kg), as well as a high concentration of polyphenols (1.2-19.0 g/L) and a low concentration of micronutrients and heavy metals. Because these features are incompatible with agricultural standards, the waste must be conditioned before use [54]. The chemical composition of grape stalks (leaves and shoots), grape seeds, wine lees, and grape pomace differs depending on the source [55].

Leaves of *Vitis vinifera* L. are a less studied and less valorized by-product of grape crops and the winery business. According to the minimal information available, it contains phenolic acids, organic acids, flavonols, tannins, procyanidins, anthocyanins, vitamins, enzymes, carotenoids, lipids, terpenes, and reducing or non-reducing sugars [56].

Grape pomace is a solid waste product generated during the early stages of grape juice manufacturing that contains both water-soluble and water-insoluble components. It has a high moisture content of 40-81% and contains a substantial number of insoluble residues as well as protein, cellulose, and pectin components [55]. Table 1 shows the estimated composition of grape pomace [57].

Table 1

Estimated chemical composition of grape marc

Compounds, %	Raw grape marc	Dried grape marc
Crude protein	12.4	13.6
Crude cellulose	22.5	24.7
Crude lipids	5.4	6
Mineral	6.7	7.4
Insoluble ash	1.3	1.5
Fibers - hemicellulose, cellulose and lignin	55.4	60.8
Fibers - lignocellulose	48	52.6
Lignin	30.8	33.7
Cell membrane	54.6	59.9
Starch	1	1.1
Total sugars,	2	2.2
Energy, MJ//kg	17.4	19.1

Insoluble residues contain a lignin percentage ranging from 16.8 to 24.2% and a protein level of less than 4%. Peptic compounds are the primary polymer-type constituent of the cell walls present in grape pomace, accounting for 37 to 54% of the cell wall polysaccharides, while cellulose concentration ranges between 27 and 37% [58].

Water-soluble substances include polysaccharides, oligosaccharides and monosaccharides, whereas cell wall participating polysaccharides do not demonstrate solubility in water [55]. When we look at its composition, grape pomace is distinguished by its appropriateness for usage in a variety of industrial processes, including the extraction of grapeseed oil and polyphenols, the fermentation of citric acid, methanol, ethanol, and xanthan, and the generation of energy by methanisation. Grape pomace contains phenolic acids, flavan-3-ols, flavonols, anthocyanins, and proanthocyanidins as the primary polyphenols [59].

Wine lees are the remnants that form at the bottom of wine production tanks after fermentation, storage, or further treatment. The lees' usual composition includes yeast, tartaric acid, phenolic chemicals, and other inorganic elements [60]. The sediment that forms when the must ferments must be eliminated. In extreme cases, this can result in waste levels of up to 20% of the harvested grape mass. In some cases, separation procedures can reduce the amount of sediment that forms during fermentation. Yeast sediment is mostly composed of yeast cells and tartar. Their quantities differ depending on the type of wine produced [61]. Wine lees contain both liquid and solid components. The solid parts of wine lees contain cellulose, hemicellulose, lignin, seeds, grains, and organic and inorganic salts.

Vinasse is the liquid part of wine lees generated from residual fermentation broth. It is the principal source of polyphenol compounds and contains around 58% water by weight, with a pH of 3.5 [55]. Vinasse should be used shortly after distillation and clarifying of wine.

Today's society is particularly concerned with the sustainable management of agricultural soils and the water supplies that support them. This setting includes agricultural properties dedicated to wine production. In quantitative terms, each tone of grapes processed produces approximately 3000–4000 L of effluent. The use of wastewater for farm irrigation is being implemented throughout the country, and for it to be acceptable, it must be pre-processed at various levels [54].

3.2 Analysis of the experience of applying the circular bioeconomy to wine enterprises

The concept of circular economy is not yet claimed as incorporated in a lot of studies while being mentioned as a vital topic for future research. In some cases, it was confirmed that, even though the plant did not include in policies a definition of circular economy, the concepts are, in some way, present, particularly with the concern about reducing waste disposal through treatment and recovery, making the best use of resources at all stages of the chain process, and the need to rethink and redesign current practices with sustainability in mind [62].

One enterprise established in 1969 in France to protect the survival of the region's wine cooperatives demanded winemakers to provide their waste from production for distillation in 1970. Since 1994, the company has been diversifying its new products and ingredients into new markets, the food and pet food industries, and nutraceutical enterprises, transforming itself into a small 'biorefinery' with the incorporation of modern

bio- and extraction technologies. In 2007, a regional expansion was planned to reach a critical mass of waste, significantly altering logistic supply and demand networks [63].

The Italian wine business can serve as a perfect model for the use of bioeconomy principles, such as the valorization of agricultural and food waste, in the problem of transforming waste into valuable products that can be re-used cyclically. To valorize winery leftovers and enhance overall environmental performance, two side production chains (grapeseed oil and tartrate production) were integrated, and circular patterns were devised and implemented in the traditional production chain [64, 65]. The holistic use of all winery by-products, such as grape stalks, grape pomace, and wine lees, could lead to the establishment of integrated biorefineries for the production of a wide range of goods with diverse market outlets [66].

A performance measurement system can play in tracking the contribution of circular economy partnerships to the sustainability of an agro-waste valorization wine value chain. Furthermore, analyzing the progress of the circular economy concept helps to analyze the responsible production of sustainable development targets at the supply chain level [67].

4. Biotechnologies applied for the capitalization of wine by-products

It is proposed bioconversion as one of convenient ways of winemaking waste valorization. A comparative analysis of bioconversion of various forms of waste demonstrates that cellulose microbial enzymatic degradation is the most effective for grape pomace in waste, allowing us to acquire valuable feed additives while lowering the environmental risk level [68]. Fermenting grape pomace using *Aureobasidium pullulans, Scelorotium glucanium* and *Xanthomonas spp*. strains is used for obtaining microbial polysaccharides [69]. Also, vine shoots might be a suitable feedstock for the manufacture of xylooligosaccharides and galactooligosaccharides [70].

Grape stalk hydrolysis methods produced liquors with varying concentrations of fermentable sugars, which were utilized by *Debaryomyces nepalensis* to produce industrial metabolites. The predominant product of *Debaryomyces nepalensis* growth was ethanol, followed by lactic acid and xylitol in the presence of xylose, which was produced mostly when glucose was exhausted [71].

Fructose and glucose are abundant in white grape pomace, which can be used as a carbon source throughout the fermentation process. *Lactobacillus casei* produced lactic acid, which was used to valorize this waste. 33.3 g/L of lactic acid was produced by adding white grape pomace directly or as a water extract to the growth medium at a solid dosage of 10%. White grape pomace is a viable plant-based feedstock that *Lactobacillus casei* can use to produce lactic acid [72]. Lactic acid can be also produced by fermenting grape vine lees with *Lactobacillus rhamnosus* and *Lactobacillus pentosus* strains [69].

Vinegar has several uses in the food industry, including use as an acidifier, flavor enhancer, pH control agent, flavoring agent, and pickling agent. Because of their high sugar content, grapes and their residues are suitable raw materials for vinegar manufacture by anaerobic and aerobic fermentation [69].

The possibility of using grape pomace as a substrate for the generation of citric acid has also been looked into using solid-state fermentation methods. When *Aspergillus niger* NRRL 567 species fermented grape pomace, the yield was around 600 kg/m^3, whereas *Aspergillus niger* NRRL 2001 species produced a yield of 413 kg/m^3 [73]. Using grape must as a nutrient source, research established the growth and citric acid production

characteristics of two *Yarrowia lipolytica* strains. This natural source was shown to be a promising substrate for the citric acid manufacturing process [74].

Agro-food waste can be utilized by microorganisms to make industrially useful enzymes. There are a few studies in the literature on the use of grape pomace for the synthesis of the enzymes pectinase, cellulase, and xylanase by various *Aspergillus* species [73]. For industrial manufacturing of the pectinases, cellulases and xylanases enzymes, *Aspergillus awamori* strain is utilized as well as grape pomace as a substrate [69]. Cellulolytic enzymes can also be produced using grape stalks [75].

Grape waste demonstrated potential as a substrate for the generation of single-cell protein and protein-rich fungi by a variety of microorganisms [73].

Compared to typical chemical catalysts, microbial enzymes are crucial in the valorization of agro-industrial crops and food wastes. It holds enormous potential for effective waste utilization and adequate biocatalytic systems with high conversion efficiencies, allowing the realization of the goals of sustainable development [76].

5. Use of products obtained from wine waste in the food, pharmaceutical and cosmetics industries.

5.1 Pharmaceuticals

Agro-industrial by-products contain a high concentration of bioactive chemicals. It is suggested that combining agro-industrial by-product extracts with a traditional technique could constitute a new strategy for preventing or treating obesity and multiple sclerosis [77].

Employing an atherosclerotic environment model, pressurized liquid extraction enabled the development of stem and seed extracts with significant anti-inflammatory activity. These extracts have a high potential for application as natural components in the creation of anti-atherogenic products. Furthermore, these findings raised the usefulness of winemaking by-products as a source of natural anti-atherogenic chemicals [78].

Studies show that regarding affecting glucose metabolism, it is important to mention, that a single dose of grape juice does not significantly alter glucose metabolism; regular ingestion remains to be investigated [79]. Nevertheless, according to another research, taking two capsules of grape pomace extract twice a day for three weeks reduced blood fasting glucose levels significantly. The *in vivo* regulation of targeted miRNAs linked to glucose metabolism found after grape pomace extract consumption implies a possible role for grape pomace in glucose metabolism, which would lead to a lower risk of type 2 diabetes. Despite this, significant increases in the production of certain short-chain fatty acids and significant decreases in medium-chain fatty acids were seen with grape pomace administration [80]. Grape shoot extracts inhibited α-amylase and acetylcholinesterase enzymes, indicating their potential for application in the treatment of Alzheimer's and diabetes. According to high-performance liquid chromatography analyses of the phenolic profile was the significant contributors to the antioxidant and biological activities of the vine shoot extracts [81].

The first digestion of grape pomace extracts using a dynamic gastrointestinal digestion model was reported [82]. Simulator gastro-intestinal (SIMGI) was created to simulate the actual digestion and fermentation processes. The system consists of three-stage culture reactors designed to simulate the microbial conditions of various parts of the human large intestine *in vitro* [83]. The primary bioaccessible phenolic metabolites produced from grape pomace extract were discovered to be various benzoic, phenylacetic,

and phenylpropionic acids. Furthermore, from the SIMGI stable microbiota, a bacteria strain capable of metabolizing (-)-epicatechin gallate, a phenolic molecule found in grapes and wine, was recovered and identified as *Raoultella ornithinolytica* or *Raoultella planticola*. In conclusion, feeding the SIMGI with grape pomace extract increased the metabolic activity of colonic microbiota, particularly during chronic feeding, resulting in a large number of bioaccessible phenolic metabolites. Concurrently, grape pomace extract feeding caused microbial alterations, particularly in the *Lactobacillus* and *Bacteroides* species. Grape pomace extracts are promising candidates for the creation of innovative products with gut microbiota-related beneficial qualities [82]. There is compelling evidence that phenolic compounds can influence the composition of the gut microbiota in humans, hence enhancing a range of biochemical indicators and risk factors for chronic diseases. According to the available literature, metabolites of phenolic compounds generated by gut bacteria, including probiotics, provide a variety of health benefits. These metabolites are more active than their parent food phenolic substances [84].

Microbiological valorization and reutilization of grape marc are based on the biomass synthesis and delivery of antioxidant chemicals by lactic acid bacteria and bifidobacteria [85]. The oligosaccharides found in grapes were examined as potential functional components with prebiotic activity [86].

Strained lees of wines made from crimson glory vine berries could be used effectively as auxiliary materials for the development of interesting sources of natural antioxidants and angiotensin-converting-enzyme and hyaluronidase inhibitors for the prevention and treatment of allergy and lifestyle-related diseases [87]. Anthocyanins have been proven to reduce creatine kinase, muscular pain, and strength loss, and improve power after exercise. Following anthocyanin consumption, there was less inflammation and an increase in antioxidant capacity/status, indicating a possible causative relationship. Subgroup analyses revealed that metabolically biased exercise and longer-term interventions have the most beneficial effect on biomarkers, whereas shorter duration interventions have the most benefit on physiological variables, which can help inform research designs and the application of anthocyanins in exercise recovery. These findings give additional evidence to support the use of anthocyanin-rich meals in boosting recovery after severe exercise, which can help exercisers and practitioners [88]. According to the literature, certain types of stress might change flavonoid metabolism and intracellular accumulation. To move away from the universal approach to dietary recommendations and toward science-based individualized nutrition, further mechanistic research on the impact of health status on flavonoid responses under physiologically relevant micro-environments is needed [89].

The polyphenol-based grape extract suppresses adenovirus Ad-5 replication irreversibly. These findings support the use of polyphenol-based grape extract and Resveratrol as possible sources of promising natural antiviral medicines against adenovirus Ad-5 infection [90]. Also, it was proven that polyphenols are a promising natural therapeutic for both preventing microbial-derived oral diseases and maintaining oral health [91].

A rising number of researchers are currently focused on the biological activities of grapes and grape derivatives as potential sources of useful nutraceuticals. Numerous studies have strongly shown that incorporating grapes and grape products as supplements into our daily diets may result in considerable health advantages. Most of these phytochemicals, however, must be utilized in a precise dose-dependent way to elicit

favorable therapeutic effects. Bioavailability *in vivo* is a critical problem to address before determining the level of therapeutic blood concentrations of grape flavonoids. As a result, more research in this area is required. Future discovery of novel renewable sources, such as *in vitro* cell systems capable of continually producing highly pure grape flavonoids, is critical and potentially widespread [92]. Future research should and will include the validation of appropriate biomarkers of effect antioxidant, new cellular and molecular targets, the precise contribution to dietary profiles, and further clarification of *in vivo* biotransformation, including analyses of metabolite biological effects, and the formulation of pro-drugs [93].

5.2 Food industry - technologies and drawbacks

Inedible raw materials can be transformed into more useful, shelf-stable, and pleasant foods or drinkable liquids for human consumption by food processing. Some of the advantages of food processing for phytochemicals include increased bioaccessibility, shelf-life extension, improved sensory features, and functional properties. Phytochemicals may produce more beneficial molecules during food processing as a result of physical or chemical changes. Fermentation, for example, produces a variety of secondary metabolites, some of which have been linked to health benefits. During polyphenol fermentation, some small-molecule organic acids (e.g., citric, malic, lactic acid) are also formed, enhancing iron and zinc absorption via the creation of soluble ligands [94]. Food processing may improve phytochemical bioaccessibility in the following ways: increasing liberation from the food matrix, improving micellization of some hydrophobic phytochemicals, improving phytochemical synthesis, increasing absorption in the gastrointestinal tract, and improving phytochemical stability [94].

Depending on the dosage, the form of the by-product (powder or extract), and the dairy matrix in which it is integrated, the inclusion of fruit and vegetable by-products can have either good or negative impacts on the sensory qualities of the final product [95]. Regarding winemaking by-products, according to several studies, freezing fruits before jam production or adding benzoate do not affect anthocyanin concentration or color when compared to untreated fruits. Furthermore, other factors, such as the addition of ascorbic acid or other natural phytochemicals, did improve the color and sensory qualities of anthocyanin-rich goods [94]. The use of anthocyanins from natural sources is thus approved by European Food Safety Authority (EFSA) and Food and Drug Administration (FDA) [96,97]. Due to a lack of characterization and toxicity data, EFSA did not develop an average daily intake (ADI) for this colorant; hence, consumption as an additive should not exceed the typical intake of these substances. JECFA has not assigned ADI to anthocyanins derived from grape skin extract [98].

It has been established that new green technologies such as pulsed electric fields, ultrasounds, microwaves, high hydrostatic pressure, and supercritical fluid extraction may produce high-quality extracts. These extraction procedures, when combined with purifying operations with resins and membrane processes, result in anthocyanin-rich extracts with lower impurity levels [99]. Furthermore, in terms of anthocyanin recovery, it should be highlighted that encapsulation has been recognized as one of the most significant ways of stabilizing these molecules, particularly given the decrease in anthocyanin concentration in fortified products after thermal treatment and storage [99].

Encapsulating agents operate as a shield against harmful environmental factors such as light, humidity, and oxygen. Bioactive substances that have been encapsulated are easier

to handle and have a higher degree of stability. Encapsulation techniques are already widely used to limit interactions between food and medical components and environmental elements like temperature, light, moisture, and oxygen. Microencapsulation of anthocyanins with a mix of maltodextrin and gum arabic resulted in the best encapsulation efficiencies. Spray-drying is a typical process for microencapsulating isolated plant phenolics like anthocyanins. Polysaccharides and other matrix materials such as glucose syrup and soy protein isolate are commonly employed [100].

Peanparkdee et al. had determined that in the case of baked products, the addition of anthocyanin-rich extracts can protect the food from damage caused by baking, while improving its antioxidant capacity. Anthocyanins have good stability during storage in products such as kefir, yogurt, and various beverages, making them suitable foods for anthocyanin fortification. The inclusion of anthocyanins improved the color of processed meals, indicating a feasible alternative to synthetic colorants [99].

It is important to mention that many phytochemicals are lost during food preparation. This process usually occurs in two ways, one of which results in the direct generation of by-products or waste. Some hydrophilic phytochemicals, for example, may be lost while soaking. During the juicing process, some insoluble phytochemicals may be discarded as waste. Others may be damaged or oxidized as a result of chemical changes (food processing frequently causes the breakdown of phenolic chemicals, lowering their concentration in processed meals). As a result, the canning process entails a significant loss of water-soluble and heat-sensitive components, resulting in a lower level of phenolic compounds when compared to the original fresh fruit and vegetable [94].

Unwanted food processing may result in the formation of substances that have a negative impact on the texture, flavor, or color of phytochemical-rich goods, or even cause human health risks. However, by utilizing proper technology, it is possible to optimize food formulations, processing technologies, and preparation processes to reduce or even eliminate their production [94].

The addition of natural substances may affect other qualities such as flavor and odor. Kaimainen et al. assessed the acceptability of natural colorants based on betalains from beetroot and anthocyanins from grapes in different concentrations in model juice. It was discovered that increasing the concentration of beetroot powder as a colorant reduced significantly the acceptability of the attributed flavor, making the product unpleasant and strange, which did not occur with the addition of anthocyanins. However, the same impact was observed when grape marc power was mixed into fettuccini pasta [98]. Natural pigments diffusion in real meals is influenced by a variety of parameters, including composition, pH, water activity, packaging material, and the presence of trace metals. The usage of natural pigments in meals at the concentration levels required to achieve the desired color intensity and hue may result in unacceptable alterations in the product's organoleptic quality [101].

Natural pigments' stability requirements limit their employment in food matrices, such as anthocyanins, which are more stable in foods with low pH. Anthocyanins from grape by-products were added to kefir (pH 4.5) and carbonated water. The authors concluded that the kefir product had better color stability because the half-life time of the total anthocyanins was 27 days, whereas the carbonated water half-life time was shorter (only 6 days), which could be influenced by the type of food matrix over the anthocyanins' stability [98].

Published literature data on the use of encapsulated natural pigments as coloring agents in food products is relatively limited. According to several recent studies, the bioaccessibility and stability of encapsulated plant polyphenols vary depending on not just the encapsulation process and carrier agent, but also the kind of polyphenol. Plant polyphenols encapsulated have the potential to be used in food products. It is also critical in the food business to examine the stability of encapsulated phenolic compounds during food processing [102].

6. Conclusions

The current technological level allows variable ways of winemaking waste treatment, creating different eco-sustainable and bio-based materials (biobased polymers, biofuels, bioactive compounds extracts, grapeseed oil, fertilizers, tartaric acid, and sorbents) with a broad range of application. Those value-added products not only solve the problem of waste disposal but also potentially bring profit to the wineries. Despite traditional methods of treatment being cost-effective or showing high yields, the modern industry should focus on more eco-friendly and sustainable technologies, which are currently proposed by scientific studies.

At the moment, the production of tartaric acid is the most priority for the processing of winemaking by-products for the Republic of Moldova, due to the availability of sufficient raw materials and the high need for use in wine production.

Biogas production takes place only in the case of complex bioprocessing enterprises in order to cover part of the energy costs since its transportation is not advisable.

Production of biobased polymers from winemaking waste opens up a vast opportunity in different practical applications of the final product, with the future possibility of its recycling and decomposition.

Manufacturing of sorbents (activated carbon and biochar) not only solves the issue of organic winery waste disposal but also will benefit in clearing the polluted wastewater, and preserving the freshwater basin, which is vital for the ecology and biosphere as a whole.

Grape pomace is considered to be a good substrate for production of industrial microbial metabolites, because of the high carbon content.

The grape pomace extracts, depending on the processing method, have a high potential in manufacturing profit-generating pharmaceuticals with anti-inflammatory properties or prebiotic formulations due to the polyphenol-rich composition of this raw material.

The incorporation of grape pomace powders or extracts have a high potential for creating functional foods, avoiding the utilization of synthetic antioxidants and colorants. Nevertheless, those technologies still have drawbacks to be solved. Encapsulation should ideally not only help to overcome any instability issues that may impair the efficacy of the coloring, but also make their integration into foods easier.

The Moldovan legislation in force considers the valorization and recycling of winemaking wastes. Nevertheless, the list of products that are allowed for production is limited and needs reconsideration. The elaboration of plant-scale technologies and state quality standards for new value-added products will allow producers to solve the waste disposal problem and attract investments, both national and international in this business domain.

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BERRY AND GRAPE METABOLITES FOR ANTIMICROBIAL APPLICATIONS AGAINST FOODBORNE BACTERIAL PATHOGENS

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Abstract. The increase in the resistance of microorganisms to chemical substances and conventional drugs presents a serious and obvious problem worldwide, which has determined numerous researches aimed at the identification of new biocides with extended activity. Plants and their derivatives contain a wide variety of secondary metabolites that can inhibit or slow down the growth of bacteria, yeasts and molds. The microbiostatic activity of some berries represents a promising source of alternative solutions for their use in order to reduce the microbial contamination of raw materials and food products. The article elucidates the *in vitro* microbiostatic and microbicidal effects of some berries and grape marc rich in phenolic compounds with microorganisms that cause food spoilage: *Staphylococcus aureus, Escherichia coli and Klebsiella pneumoniae*. The composition of the extracts is examined, and possible mechanisms of antimicrobial action are analyzed.

Keywords: *berries, grape marc, phenolic compounds, antimicrobial activity, mechanisms of inhibition of pathogenic bacteria.*

Rezumat. Creșterea rezistenței microorganismelor la substanțele chimice și medicamentele convenționale prezintă o problemă serioasă și evidentă la nivel mondial, ceea ce a determinat numeroase cercetări care vizează identificarea de noi biocide cu activitate extinsă. Plantele și derivații lor conțin o mare varietate de metaboliți secundari care pot inhiba sau încetini creșterea bacteriilor, drojdiilor și mucegaiurilor. Activitatea microbiostatică a unor fructe de pădure reprezintă o sursă promițătoare de soluții alternative pentru utilizarea acestora în vederea reducerii contaminării microbiene a materiilor prime și a produselor alimentare. Articolul elucidează efectele microbiostatice și microbicide *in vitro* ale unor fructe de pădure și tescovină de struguri bogate în compuși fenolici cu microorganisme care provoacă alterarea alimentelor: *Staphylococcus aureus*, *Escherichia coli* și *Klebsiella pneumoniae*. Se examinează compoziția extractelor și se analizează posibilele mecanisme de acțiune antimicrobiană.

Cuvinte cheie: *fructe de pădure, tescovină de struguri, compuși fenolici, activitate antimicrobiană, mecanisme de inhibare a bacteriilor patogene.*

1. Introduction

Antimicrobial-resistant microorganisms present in humans, animals, in food and in the environment is a complex epidemiological problem [1,2]. The epidemiological surveillance system of antimicrobial resistance in the Republic of Moldova is based on the surveillance of the traffic of microbial agents identified from patients and provides only partial and unsubstantial data.

National results on antibiotic susceptibility of pathogenic microorganisms isolated from people show a concerning resistance to compounds included in national protocols for first-line therapy [3]. Primary and secondary multidrug-resistant tuberculosis have high rates of 26% and 64%, respectively, compared to an average of 12% and 50% in the World Health Organization European region. Approximately 60% of strains of microorganisms isolated from patients with surgical wound infections are resistant to antimicrobials. The medication for common diseases such as pharyngitis, bronchitis or food poisoning caused by bacteria fails due to the irrational and excessive use of antimicrobials. The information on the antimicrobial sensitivity of microbial agents shows their significant resistance: every third strain of *Staphylococcus aureus* is resistant to tetracycline (30.4%), clindamycin (35.2%) and erythromycin (38.4%), and approximately two out of three strains of *Streptococcus pneumoniae* are resistant to co-trimoxazole (59.6%), cefaclor (61.3%), oxacillin (64.9%) [4].

Antimicrobial resistance is not exclusively a public health problem, but also an animal health problem with direct economic consequences. The phenomenon of antimicrobial resistance causes a decrease in the effectiveness of antimicrobial treatment in animals, as well as the transmission of resistant bacteria through the food chain and from animals to humans. The concept of antimicrobial resistance also addresses food safety, as antimicrobial-resistant microorganisms and genes spread from animals to humans through the food chain. The emergence of resistant strains of *Salmonella* and *Campylobacter* is caused by the use of antimicrobials in animal husbandry, resulting in cases of human diseases following the consumption of unsafe food, therefore a unified approach to antimicrobial resistance in the world, as well as in the Republic of Moldova, is absolutely necessary [5].

The emergence of multidrug-resistant bacterial strains and the emergence of strains with low sensitivity to antibiotics have led to resurgence of research interests in the discovery of new antimicrobial agents from natural sources that can be used for therapeutic and prophylactic purposes against microbial diseases, such as food preservatives and additives for animal feed. Plants contain a wide range of phytochemicals, which have been traditionally used for centuries traditional medication or ethnomedicines [6].

Thus, the increasing resistance of microorganisms to chemical substances and conventional medicines is a serious and evident problem worldwide, that drives research aimed at identifying new biocides with extended activity. Plants and their derivatives contain a wide variety of secondary metabolites that can inhibit or slow the growth of bacteria, yeasts and molds [7]. The microbiostatic activity of some vegetables represents a promising source of alternative solutions for their use in order to reduce the microbial contamination of raw materials and food products. Berries and plants are an important source of phenolic compounds in the daily diet, and the market for berries has grown over the years due to their contribution to public health. Natural products from berries are being studied as a new arsenal of antimicrobials and prebiotics, due to their ability to selectively inhibit food pathogens, stimulating beneficial microorganisms [8,9]. Berries are traditionally

an important part of the diet. About 50 different berries are grown in the northern regions, and about half of them are edible.

The purpose of this research is to evaluate the microbiostatic effect of the extracts of forest fruits rich in bioactive compounds on microorganisms that cause food spoilage (*Staphylococcus aureus*, *Escherichia coli* and *Klebsiella pneumoniae)* in order to explain their microbiostatic action mechanisms.

2. Materials and Methods

2.1. Materials used in research

The plant extracts were obtained from the plant matter of the following fruits native to the Republic of Moldova (RM): white sea buckthorn (*Hippophae rhamnoides* L.), rosehip (*Roza canina* L.), mountain ash (*Sorbus aucuparia* L.), hawthorn (*Crataegus monogyna*), aronia (*Aronia melanocarpa*) and grape marc (*Vitis vinifera* L.) from red varieties.

2.2. Reference strains

Staphylococcus aureus ATCC 25923; *Escherichia coli* ATCC 25922 and *Klebsiella pneumoniae* ATCC 13883 obtained from American Type Culture Collection (ATCC), National Agency for Public Health. The reference strains used are cataloged, characterized bacteria with stable, defined antibiotic susceptibility phenotypes. They are used for internal quality control.

2.3. Reagents

Chromatographic purity reagents were used to carry out the research (Sigma-Aldrich (Merck KGaA, Darmstadt, Germany); ethyl alcohol - LC-MS grade Carl Roth (Karlsruhe, Germany).

2.4. Preparation of extracts

To obtain the extracts, the berries were dried at room temperature (20. ± 1.0°C) to a final moisture content of 8.0 ± 1.0%. For extraction, the dry substance was ground and sieved into powder. The extraction process was carried out by two methods: shaking and ultrasound, observing two temperature regimes: 20.0 ± 1.0°C and 45.0 ± 1.0°C and 3 time periods: 0.5h, 1 ,0h and 1.5h [10]. The plant matter to solvent ratio was determined experimentally and depends on the type of plant matter: rosehip (1:15), sea buckthorn and mountain ash (1:12), hawthorn (1:20) and aronia (1:18). To decant the extracts, the obtained samples were centrifuged at 7000 min^{-1} for 10 minutes. The obtained extracts are stored in dark glass bottles at 4°C.

2.5 Analysis of individual bioactive compounds from berries and grape pomace extracts

The tests were performed through the chromatographic method (HPLC, Agilent 1100 Series) [11]. The mobile phase included eluent of 1% CH_3OH (solvent A) and 50% CH_3OH (solvent B), acidified to pH 2.15 with trifluoroacetic acid (TFA). The column system included Security Guard ULTRA HPLC C18 precolumns and C18 100 Å 250×4.6 m columns manufactured by Phenomenex. The injection volume was 20 µL and the detection time was 90 min. Detection was performed at 256, 280, 324 and 365 nm.

The elution gradient was 100% (A) for 10 minutes; 82%(A):18%(B) for the next 10 minutes; 70%(A):30%(B) for 10 minutes; 65%(A):35%(B) for 6 minutes; 40%(A):60%(B) for 15 minutes; 20%(A):80%(B) for 5 minutes; 100%(B) for 15 min and 100%(A) for 10 min.

2.6. Determining the minimum inhibitory concentrations (MIC) and minimum bactericidal concentrations (MBC) of natural compounds

MIC and MBC were determined through the dilution method, which allows to estimate the concentration of the tested antimicrobial agent in the broth (macrodilution or microdilution) [12]. The recorded MIC value is defined as the lowest concentration of the tested antimicrobial agent that inhibits the visible growth of the tested microorganism and is usually expressed in mg/mL. In the study, the MIC and MBC values of the natural antimicrobial agents tested on the selected strains were determined.

2.7. Statistical analysis

All experiments were carried out in three repetitions, and the obtained experimental results were subjected to the usual statistical analysis with the application of descriptive statistics tools (calculation of arithmetic means, standard deviation, coefficient of variation and correlation coefficient). As a test of significance - Student's test, being accepted as statistically true differences [13]. The statistical processing of the results was carried out with the MS Excel program. Statistical significance threshold chosen: $p<0.05$.

3. Results and Discussion

There are various *in vitro* techniques to test minimum inhibitory concentrations (MICs) and minimum bactericidal concentrations (MBCs) in order to determine antimicrobial susceptibility or resistance of microorganisms [14]. The aim of the study was to determine whether the etiological agent is resistant or sensitive to the tested natural antimicrobial agents. The MIC (the lowest concentration that inhibits visible growth of the organism), was determined based on the 90% inhibition level. The antimicrobial agent must inhibit 90% of visible microbial growth. Thus, the tested organism was called "susceptible". Following the tests carried out, it was found that the powders from sea buckthorn and sea buckthorn groats achieve a more pronounced antimicrobial activity against all the pathogenic microorganisms investigated, Table 1.

Table 1

Minimum inhibitory concentrations (MIC) and minimum bactericidal concentrations (MBC) of plant powders on pathogenic microorganisms

Plants powders	***Staphylococcus aureus* ATCC 25923**		***Escherichia coli* ATCC 25922**		***Klebsiella pneumoniae* ATCC 13883**	
	MIC mg/mL	MBC mg/mL	MIC mg/mL	MBC mg/mL	MIC mg/mL	MBC mg/mL
Sea buckthorn	1.95± 0.12	3.90± 0.23	7.81± 0.37	15.6± 0.7	15.6± 0.5	31.25± 1.25
Sea buckthorn (groats)	15.63± 0.33	31.25± 1.03	62.50± 2.37	125± 5.0	62.5± 2.1	125± 5.0
Aronia	15.63± 0.37	31.25± 0.62	-	-	-	-
Grape pomace	7.81± 0.19	15.62± 0.41	62.50± 1.57	125± 5.0	-	-

Continuation Table 1

Rosehip	3.91± 0.15	7.81± 0.21	31.25± 0.98	62.5± 1.8	62.5± 2.1	125± 5.0
Hawthorn	41.67± 0.56	83.33± 1.23	62.50± 1.87	125± 5.0	-	-
Rosehip (groats)	3.91± 0.23	7.81± 0.29	31.25± 0.71	62.5± 2.5	62.5± 2.1	125± 5.0

Note: Test values performed in triplicate, mean ± standard error, statistical analysis – ANOVA, $\alpha \leqslant 0.05$.

It has been shown that the plant powders with the lowest inhibitory and bactericidal concentration on *Staphylococcus aureus* ATCC 25923 are sea buckthorn, with a minimum inhibitory concentration of 1.95±0.12 mg/mL, followed by rosehip powder and groats (3.91±0.15 mg/mL) and grape pomace (7.81±0.19 mg/mL). In the case of *Escherichia coli* and *Klebsiella pneumoniae* only the white buckthorn powder manifests minimum inhibitory and bactericidal concentrations. Aronia does not show any activity on the Gram negative bacteria studied. Rosehip and hawthorn compounds show weak activity against *Escherichia coli* ATCC 25922, but *Klebsiella pneumoniae* ATCC 13883 is resistant to hawthorn.

The obtained results attest to the fact that, although all the examined powders are extremely rich in biologically active compounds, their direct effects on pathogenic microorganisms depend on several factors. First of all, the bacterial adhesion capacity of biologically active compounds is extremely important, and it depends on their hydrophilic character.

For the microorganisms examined, which are capable of rapidly colonizing meat products and evidently have an increased degree of hydrophobicity, the maximum inhibitory and bactericidal effect was attested in the sea buckthorn and rosehip powder, which have a considerably higher content of biologically active lipophilic compounds (lycopene, β-carotene, zeaxanthin, chlorophylls) than aronia and grape pomace powders, in which flavonoids predominate [15]. At the same time, in hawthorn, the content of biologically active lipophilic compounds is important, but the inhibitory and microbicidal effect was lower than in sea buckthorn and rosehip powder. These results prove that the presence of organic acids and active acidity have an extremely important role since they directly influence bacterial adhesion and the process of inhibiting the proliferation of pathogenic microorganisms.

Sea buckthorn presented antimicrobial effects against gram-positive bacteria such as *Bacillus cereus* and *Staphylococcus aureus*, where *Staphylococcus aureus* showed complete inhibition of bacterial growth at 250 μg/mL, *Bacillus cereus* at 125 μg/mL, *Escherichia coli* at 4 μg/mL and *Pseudomonas aeruginosa* at 300 μg/mL [16]. *Escherichia coli* was found to be more sensitive to *Hippophae rhamnoides* L. berry powder which inhibits it at very low concentration. In another study, researchers analyzed rosehip extract and determined the highest inhibitory activity against 5 strains of Gram-positive bacteria (*Bacillus cereus* ATCC 11778, *Enterococcus faecalis* ATCC 29212, *Staphylococcus aureus* ATCC 25923, *Staphylococcus epidermidis* ATCC 12228) and 5 strains of Gram-negative bacteria (*Escherichia coli* ATCC 25922, *Klebsiella pneumoniae* ATCC13883, *Proteus mirabilis* ATCC 35659, *Pseudomonas aeruginosa* ATCC 27853, *Salmonella enteritidis* ATCC 13076) [17].

Polyphenols and carotenoids serve as preservatives in food processing. Several studies have shown that antioxidants can act in various ways, including as free radical

scavengers or chelators, preventing lipid oxidation and thereby preventing nutrient loss and inhibiting the potential formation of toxic compounds [18,19]. Food spoilage and food poisoning caused by the growth of pathogenic bacteria are major problems in the food industry. There is a growing interest in the use of active natural preservatives. Thus, research into the mechanisms of antimicrobial and antioxidant action of bioactive plant compounds is of particular interest.

The effects of natural antioxidants depend on the absorption of phenolic hydrogen in radical reactions, the stability of the natural antioxidant radical formed during radical reactions, and the substituents present in the structure. An antioxidant is a molecule that reduces or prevents the oxidation of other chemicals [20]. Oxidation is part of a redox reaction and consists in the transfer of electrons from a substance to an oxidizing agent. This reaction can produce free radicals, which cause destructive chain reactions. Antioxidants are able to stop these chain reactions by oxidizing free radicals and thus blocking their action. These properties are particular to several families of chemical compounds: thiols, phenols, carotenoids, etc.

Table 2 shows the composition of individual polyphenols, identified in hydroethanolic berries and grape pomace extracts (HPLC method) [21, 22].

Sea buckthorn hydroethanolic extracts contain significant amounts of salicylic acid (24.48 mg/100 mL), hyperoside (38.53 mg/100 mL), ferulic acid methyl ester (25.43 mg/100 mL), polydatin (5.4 mg/100mL), ferulic acid (2.19 mg/100 mL), chlorogenic acid (1.43 mg/100mL), cis-resveratrol (4.17 mg/100mL) and trans-resveratrol (1.2 mg/100 mL). Rosehip extracts have important amounts of substances, such as derivatives of hydroxybenzoic acid (salicylic, gallic, protocatechuic), hydroxycinnamic acid (ferulic), flavones (catechin, epicatechin), flavonoids (procyanidin B2 and procyanidin B1), and the methyl ester of ferulic acid. The main phenolic compounds detected in aronia extract were catechin (15.41 mg/100 mL), epicatechin (4.7 mg/100 mL), ferulic acids (5.51 mg/100 mL), salicylic (2.65 mg/ 100 mL), protocatechuic acid (1.88 mg/100 mL), polydatin (1.27 mg/100 mL), ferulic acid methyl ester (1.48 mg/100 mL), but also gallic, *para*- and *meta*-benzoic acids, procyanidin B1 and B2. Grape pomace extracts contain significant amounts of procyanidin B2, gallic acid, catechin, procyanidin B1, ferulic acid and its methyl ester.

Table 2

Individual polyphenols identified in hydroethanolic berries and grape pomace extracts

Polyphenols	Sea buckthorn, mg/100mL	Rosehip, mg/100mL	Aronia, mg/100mL	Grape pomace, mg/100mL
Gallic acid	0.16±0.01	0.85±0.01	0.39±0.01	1.95±0.01
m-hydroxybenzoic acid	0.020±0.002	0.020±0.001	0.13±0.01	0.010±0.002
Protocatechuic acid	0.98±0.01	0.43±0.01	1.88±0.01	0.32±0.01
p-hydroxybenzoic acid	0.21±0.01	0.19±0.01	0.21±0.01	0.34±0.01
Gentisic acid	0.15±0.01	0.27±0.01	-	-
Vanillic acid	0.17±0.01	0.13±0.01	0.09±0.01	-

Continuation Table 2

Salicylic acid	24.48±0.05	1.07±0.01	2.65±0.02	-
Syringic acid	-	-	0.05±0.01	0.19±0.01
p-coumaric acid	0.010±0.002	0.010±0.001	0.06±0.01	-
Ferulic acid	2.19±0.01	0.32±0.01	5.51±0.03	0.82±0.01
Caffeic acid	0.006±0.001	-	0.09±0.01	-
Sinapic acid	0.13±0.01	-	0.08±0.01	0.008±0.001
Catechin	-	2.05±0.01	15.41±0.15	1.34±0.01
Epicatechin	0.37±0.01	0.49±0.01	4.7±0.02	-
Quercetin	0.030±0.005	0.020±0.001	-	0.19±0.01
Hyperoside	38.53±0.02	0.41±0.01	0.97±0.01	0.37±0.01
Procyanidin B1	0.19±0.01	0.70±0.01	0.27±0.01	1.33±0.01
Procyanidin B2	0.10±0.01	1.75±0.01	0.12±0.01	15.34±0.15
Chlorogenic acid	1.43±0.02	-	-	-
Polydatine	5.40±0.01	0.06±0.01	1.27±0.01	-
Trans-resveratrol	1.20±0.01	-	0.005±0.001	-
Cis-resveratrol	4.17±0.01	0.010±0.001	0.011±0.001	-
Methyl ester of ferulic acid	25.43±0.02	1.44±0.01	1.48±0.02	0.74±0.01

Note: results are presented as mean ± standard deviation.

Thus, it was found that the extracts used are sources rich in bioactive substances. Numerous bibliographic studies demonstrate their antimicrobial effect [23-26]. A special role in combating antibiotic resistance is attributed to natural bioactive compounds [27].

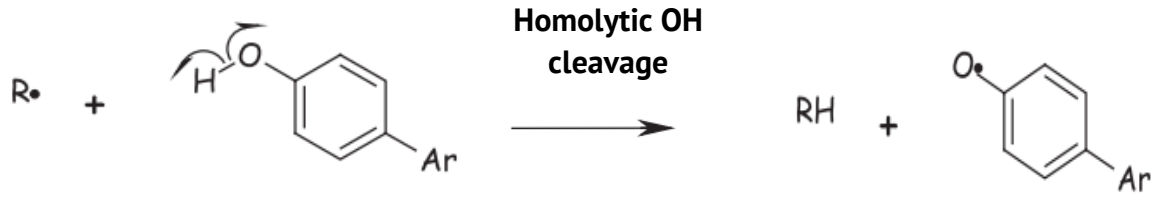
The molecular effects responsible for the antioxidant properties of polyphenols are recognized through three main mechanisms, arising from direct reaction with free radicals and from free metal chelation, the latter involved in reactions ultimately generating free radicals, Figure 1 [28].

$$ArOH + R\bullet \rightarrow ArO\bullet + RH \quad (1)$$

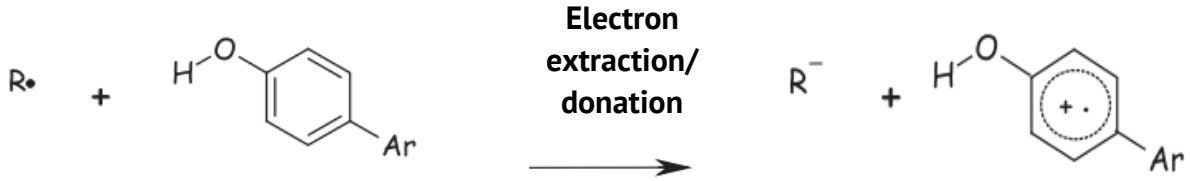
As primary antioxidants, polyphenols inactivate free radicals according to hydrogen atom transfer (HAT) (1) and electron transfer (SET) mechanisms (2) [29]. In mechanism 1, the antioxidant, ArOH, reacts with the free radical R by transferring a hydrogen atom to it by homolytic cleavage of the O–H bond.

The products of the reaction are the harmless species RH and the oxidized ArO• radical, Figure 1. Even if the reaction leads to the formation of another radical, it is less reactive than R, being stabilized by several factors.

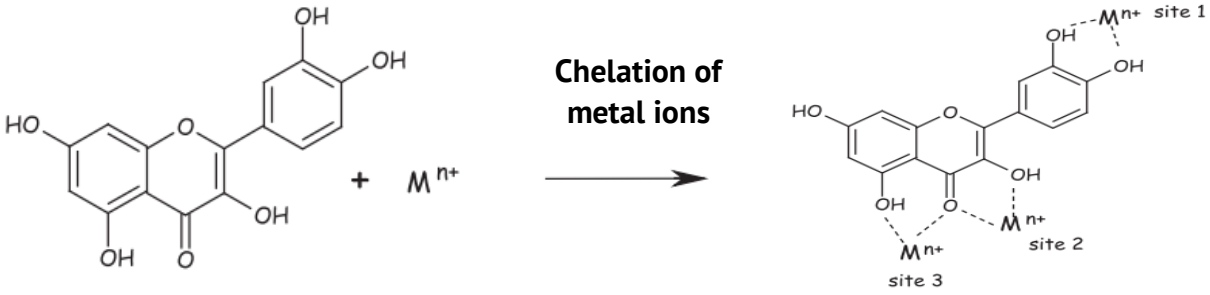
The bond dissociation enthalpy (EDL) of the phenolic O–H bond is an important parameter in the evaluation of antioxidant action.



(A) Hydrogen atom transfer (HAT) (1)



(B) Electron transfer (SET) (2)



(C) Chelation of transition metals

Figure 1. Mechanisms responsible for the antioxidant properties of polyphenols [28].

The lower the EDL value, the easier the dissociation of the phenolic O–H bond and the reaction with the free radical.

The SET mechanism (2) provides for the donation of an electron to the R• radical:

$$ArOH + R\bullet \rightarrow ArOH\bullet^{+} + R^{-} \quad (2)$$

The anion R^{-} is an energetically stable species with an even number of electrons, while the cationic radical $ArOH\bullet^{+}$ presents less reactive radical species, especially since polyphenols are aromatic structures in which the odd electron, originating from reactions with free radicals, has the possibility of being distributed throughout the molecule, resulting in radical stabilization (Figure 3.15 B) [30]. In the SET mechanism, the ionization potential is the most significant parameter for evaluating the trapping activity. The lower

the ionization potential, the easier it is to withdraw/donate electrons and react with free radicals.

Another antioxidant mechanism consists in the chelation of transition metals, capable of generating free radicals. Transition metal ions can be chelated by polyphenols, leading to stable complex compounds, Eq. (3) [31]. Some metals in their reduced oxidation state (mainly the Fe^{2+} ion) can be involved in Fenton reactions, resulting in highly dangerous reactive oxygen species (ROS) [32]:

$$H_2O_2 + M^{n+} \rightarrow HO^- + HO\bullet + M^{(n+1)+} \quad (3)$$

HO• is generally accepted as one of the most reactive radicals. It has a very short half-life (about 10^9 s) and very high reactivity. Hydroperoxides are metabolized by superoxide dismutase, but hydroxyl radicals cannot be eliminated by enzymatic reactions.

Transition metals such as copper, manganese, cobalt are able to catalyze this reaction, under certain conditions when the ions of these metals are not bound to proteins or chelators. Similar reactions can cause a specific accumulation of free radicals, which initiate the processes of damage to biomolecules. Metal chelating agents lower their redox potentials rendering them inactive. Furthermore, natural metal chelators such as flavonoids show beneficial effects on the body, while synthetic chelators may present some toxicity issues.

Within the electron transfer mechanism, the most efficient are the compounds that show planar conformation and extensive electronic delocalization, so that the values of the ionization potentials are lower than those of the reference phenol, as occurs in tocopherol, reseveratrol, quercetin. Most polyphenols appear to eliminate free radicals through the hydrogen atom transfer mechanism, since the single electron transfer process involves high energy levels. Flavonols show a stronger antiradical effect than the corresponding flavones due to the presence of the 3-hydroxyl group. The most acidic polyphenolic compounds are those characterized by a high degree of p-electron delocalization, for which deprotonation gives way to anionic species stabilized by resonance phenomena, their stability being increased by the presence of a hydrogen bond formation pattern.

Polyphenols are able to chelate transition metals via multiple OH groups and the carbonyl fragment. The flavonol quercetin, for example, can form stable complexes with Fe^{2+} and Cu^{2+} cations in both neutral and ionized form. Among the possible chelating sites, the 3-OH/4-keto and 5-OH/4-keto positions show the highest complexation capacity, while catechol appears to be a weak chelating agent.

The mechanisms of antibacterial activity of polyphenolic antioxidants are still not fully explored and several possible pathways of molecular mechanisms are proposed [33,34]. The chemical diversity of antioxidants, as well as studies conducted not on single, extracted substances, but on extracts containing several classes of compounds, make it difficult to clearly identify the molecular mechanisms responsible for inhibiting the growth of microorganisms and their death. Three main mechanisms of action of polyphenols are proposed: (a) inhibition of cytoplasmic membrane function; (b) inhibition of nucleic acid synthesis; (c) inhibition of energy metabolism [35]. Polyphenols change the morphology of bacterial cells, damage the cell wall, trigger the leakage of intracellular material. The relationship between chemical structure and antibacterial activity of antioxidants is related to the number and position of hydroxyl and methoxyl groups in the antioxidant structure. A structure-activity relationship study showed that the antimicrobial activity of polyphenols is

associated with the hydrophobic and amphiphilic nature of the molecule and the OH group in position 3 of the C ring [36]. It is considered that Gram-negative bacteria are more resistant to the effects of antioxidants, due to the presence of the lipophilic outer membrane formed by phospholipids, which makes the cell wall of these bacteria impermeable. Moreover, it is believed that Gram-negative bacteria can chemically degrade polyphenols by their enzymes [37].

One of the mechanisms of antimicrobial action of antioxidants consists in their interaction with cell wall proteins, which has the effect of damaging bacterial membranes and their permeabilization, loss of chemiosmotic control, leakage of intracellular components and eventual cell death [37,38]. Other recent studies emphasize the inhibitory properties of polyphenols in relation to biofilm production by bacteria [39]. Polyphenolic compounds appear to induce endogenous oxidative stress in bacterial cells and lead to the formation of ROS. It has been shown that ROS generated in bacterial cells are responsible for the oxidative damage of fatty acids in bacterial membranes and ultimately lead to the death of pathogens [40].

The microbiological activity of polyphenols also results from the ability of these compounds to influence the biosynthesis of proteins that are necessary for the proper functioning of bacteria. Antioxidant-dependent changes in bacterial proteins involved in, for example, energy metabolism and the tricarboxylic acid cycle, DNA metabolism and fatty acid biosynthesis lead to irreversible changes in bacterial metabolism and eventual death [40]. An important property in the context of the antibacterial activity of polyphenolic compounds is their ability to inhibit the enzyme DNA gyrase, which, in turn, leads to the inhibition of bacterial DNA synthesis [42,43]. Another enzyme essential for the energy metabolism of bacteria is ATP synthase, which undergoes a polyphenol-dependent inhibition, leading to the death of microorganisms [44,45].

5. Conclusions

The results of microbiological tests showed that different bacterial species have different antimicrobial sensitivities to the tested natural powders. In general, it has been observed that Gram positive bacteria (*Staphylococcus aureus*) to be more sensitive than Gram-negative bacteria (*Escherichia coli, Klebsiella pneumoniae*). As a result of the tests carried out, it was found that the sea buckthorn and the sea buckthorn groats powder achieve a pronounced MIC against all the pathogenic microorganisms investigated, predominantly on the Gram-positive microorganisms. Rosehip powder possesses very high antimicrobial activity against *Staphylococcus aureus* ATCC 25923. Gram-negative bacterial strains are less sensitive to the effect of berry powders. The antimicrobial activity of hawthorn is very low and *Klebsiella pneumoniae* is resistant.

The analyzed extracts contain significant amounts of bioactive compounds, belonging to different classes of polyphenols, especially derivatives of hydroxybenzoic acid (salicylic, gallic, protocatechuic), hydroxycinnamic acid (ferulic), flavones (catechin, epicatechin), flavonoids (procyanidin B2 and procyanidin B1) and esters. The molecular effects responsible for the antioxidant and antimicrobial properties of polyphenols were examined. Most polyphenols seem to eliminate free radicals through the hydrogen atom transfer mechanism, deprotonation gives way to anionic species stabilized by resonance phenomena, their stability being increased by the presence of a hydrogen bond formation pattern. Polyphenolic compounds induce endogenous oxidative stress in bacterial cells and lead to the formation of ROS. This leads to damage to bacterial membranes and their

permeabilization, loss of chemiosmotic control, leakage of cytoplasmic components, which produces cell death.

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