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THERMAL BRIDGE EFFECT OF AIR GAPS IN WALL CONSTRUCTION

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K e y w o r d s: air thermal bridges, loose mineral wool, air infiltration, thermal simulation.

A b s t r a c t

The paper presents the phenomenon of thermal bridges caused by air infiltration. The problem of poor air tightness is very common in the former Eastern Bloc countries. The laboratory investigation was set up to recognize the impact of air infiltration on heat flux through the building envelope. The frame wall model insulated with loose mineral wool was investigated in non-isothermal climatic chamber. As a result of cold air infiltration, surfaces of gaps and areas adjacent to them were cooled, which is illustrated on temperature profiles. The forty minutes infiltration of 0°C air resulted as a 3.5°C cooling of gap area. The thermal simulation in Delphin confirmed the laboratory results.

Introduction

Air infiltration is one of the most serious reasons of moisture problems in building partitions. In addition, harmful matters like microbes and radon gas transport can flow inside the building through the gaps during infiltration. In many cases the infiltration is considered as the cause of drafts, cold air inflows, and thus the loss of ventilation heating. Rarely, the researchers note another, equally important problem caused by infiltration, which is cooling of the area adjacent to the air gap, and thus creation of a thermal bridge in the problematic area. Due to mechanism of air infiltration, in which the air flows through the entire thickness of the construction with the inlet and outlet like in a channel flow, this thermal anomaly can be named as thermal bridges of air gaps and should be analyzed in conjunction with the traditionally perceived thermal bridges. In the paper there are presented selected issues of identifica-

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tion of thermal bridges caused by air infiltration (ATB). The work includes laboratory investigation results of ATB and validation of the experiment in the Delphin software. Simulation model benchmarked in the paper will be used in future work to assess ATB values.

Air flow through the gaps in building envelope

Air filtration through the building envelope arise as a result of pressure difference on both sides of the partition and can be caused by nature forces, i.e., thermal buoyancy, wind, or by an internal air distribution system. Air leaks can occur in many zones of the building envelope, i.e., gaps occurring in the joinery windows and doors, construction joints, contacts of materials of different texture and structure, holes for the installation systems and many others. Potential leaks, gaps and cracks in a building envelope can be caused by building exploitation or due to improper manufacture of elements.

Air flow through the gaps in building envelope are the objects of interest for many researchers. In most cases, these studies, relate primarily to the impact of air filtration for an efficiency of ventilation, pollutants distribution in rooms and moisture content inside building elements. Changes in the processes of heat transfer and temperature distribution in the gaps and their surroundings are less frequently described. Deseyve, Bednar described the laboratory investigation of heat losses during wind washing the fibrous roof insulation. 5 m/s wind speed can increase heat transfer through a roof by 9 times (DESEYVE, BEDNAR 2008). Kalamees, Kurnitski, Vinha et al. described Blower Door airtightness measurements in 37 Finnish buildings. Pressure air tightness measurements were supplemented by infrared radiation detection. Authors suggested that some air leakages, especially round the windows, overlap with thermal bridges (KALAMEES et al. 2008). Dufour, Derome and Zmeureanu used thermography to measure in laboratory conditions the surface temperature of single-layer walls subjected to air flow through surrogates of cracks. Authors solved an inverse problem and using developed image-processing methods of recorded thermograms (i.e., the edge detection technique and correlations for peak height and missing attenuation) to estimate the dimensions of cracks with an error of lesser than 4% (DUFOUR et al. 2009).

Air filtration through a building envelope is particularly significant in buildings located in the former Eastern Bloc countries. Traditional constructions in these countries did not include air and wind barrier layers in building partitions. As a result of aging and watering, thermal fibre materials swell and creep which lead to constriction of ventilation gap between insulation and cladding. Former Eastern Bloc countries have not participated in the oil crises

of 1970s' and that may be the reason why a problem of airtightness was not noticed there relatively quickly (BOMBERG, ONYSKO 2002).

Depending on the pressure difference through the building envelope the flow may be directed inwards or outwards. Both can cause moisture problems and energy losses. It can be assumed that infiltration occurs in a half of air leaks. Air thermal bridges occur mostly in joints of lightweight construction but appear in the other places as well. ATB, for example, often occurs in the traditional construction of attics. In a single building there are at least few hundred meters of joints between the cladding boards. These joints are the potential air leaks and therefore in many cases – ATBs (WÓJCIK, KOSIŃSKI 2014, KOSIŃSKI 2014).

Air flow through the gaps in building envelope – the heat flux calculation

Heat transfer coupled with air mass transport may occur in gaps and in porous materials. It means that a classical method of computing the heat transfer coupled with air mass transport, only by the Fourier law, should be modified by adding an equation describing the air filtration. It was described by GRUNEWALD, NICOLAI, ZHANG (2007) and by KUBIK (2008). For this reason, the local energy balance including convective heat transfer, can be described as a differential equation (1):

$$\frac{\partial}{\partial t}(\rho U) = \nabla \cdot \left(\lambda \nabla T + \kappa \frac{c_p \Delta T}{\nu}(\nabla p + \rho g)\right) + \rho r \tag{1}$$

where:
ρU – the internal energy density [J/m^3],
λ – the heat conduction coefficient [W/(m · K)],
∇T – the temperature gradient [K/m],
κ – the intrinsic permeability of porous medium [m^2],
c_p – the specific heat of dry air [J/(kg · K)],
ΔT – the temperature difference [K],
ν – the kinematic viscosity of air [m^2/s],
∇p – the pressure gradient [Pa/m],
ρ – the dry air density [kg/m^3],
g – the gravity acceleration [m/s^2],
ρr – the internal heat source density [W/m^3].

Laboratory experimental set-up of thermal bridges caused by air infiltration

The laboratory investigation was performed in non-isothermal climatic chamber, which was specially constructed to carry out the research of the impact of air filtration on heat transfer through buildings elements. The chamber consists of two sections: a hot and a cold one. In cold part there is placed a fan system to generate wind (Fig. 1). Natural dimensions specimen is mounted in climatic chamber between cold and hot parts. An investigation analyzed in this work was a part of another experiment, so on Figure 2 there is shown the selected specimen area corresponding to current investigation.

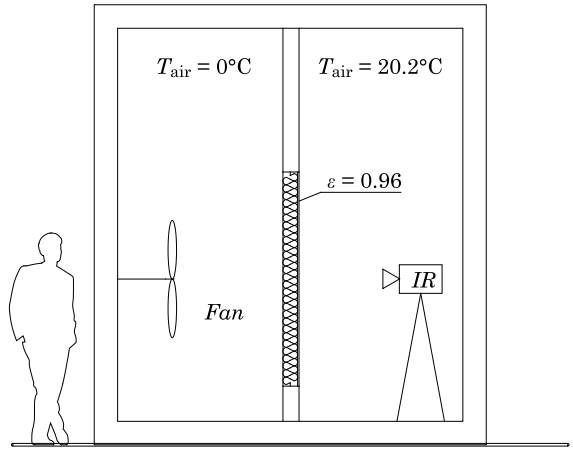

Fig. 1. Schematic representation of the laboratory set-up

Due to presenting the impact of air filtration on the air temperatures' distribution in a wall, there was prepared a light frame partition. A wall filled with loose mineral wool and aluminum support structure was constructed in the climatic chamber. Inner cladding was made with gypsum boards, which were mounted with a 3 mm gap between them. The surfaces of boards were painted in order to achieve the emissivity $\varepsilon = 0.96$. In the specimen wall, an air barrier, vapor retarder and external cladding where not mounted in order to achieve total exposition for wind force. This extreme situation corresponds to the actual conditions found in traditional buildings located on the area of the former Eastern Bloc countries. Many steep and mansard roof construction do not include wind and air barriers. In order to achieve a natural situation of the partition insulated with loose mineral wool fibers in existing buildings, the thermal insulation was initially compacted manually. During the experiment,

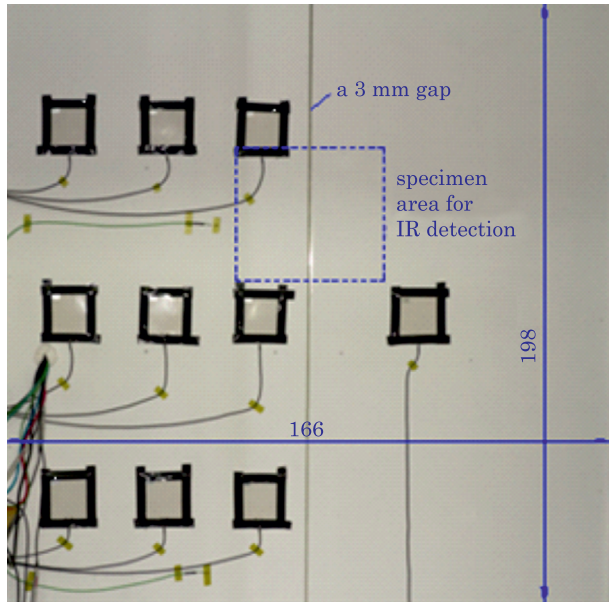

Fig. 2. Front view of the specimen with selected area for IR detection

the temperature on both sides of the specimen was measured using thermocouples while wind speed was measured by the cold side of climatic chamber using thermo anemometers. There was used Ahlborn system for acquisition data. The pressure difference was measured by the differential pressure gauge DG 700. In the table 1 there are summarized properties of the materials used in the model.

Table 1

Properties of building materials used to construct laboratory model

Layer	Conductivity, [W/(m ·)]	Thickness, [m]	Airtight	The intrinsic permeability of porous medium κ [m^2]
Gypsum board	0.22	0.0125	YES	–
Mineral wool	0.036	0.125	NO	$4.42 \cdot 10^{-5}$

The internal temperature (on the warm side) was set at 20.2°C, the outer temperature (cold side) was set at 0°C. After reaching the thermodynamic equilibrium the system of fan started to generate wind. Wind speed 3.2 m/s corresponds to pressure difference $\Delta p = 5$ Pa. Measurement procedure consisted of infrared detection on hot surface of specimen wall and temperature data acquisition using thermocouples mounted on the specimen. IR measurement were conducted using FLIR SC7200 system, which consists of infrared detector

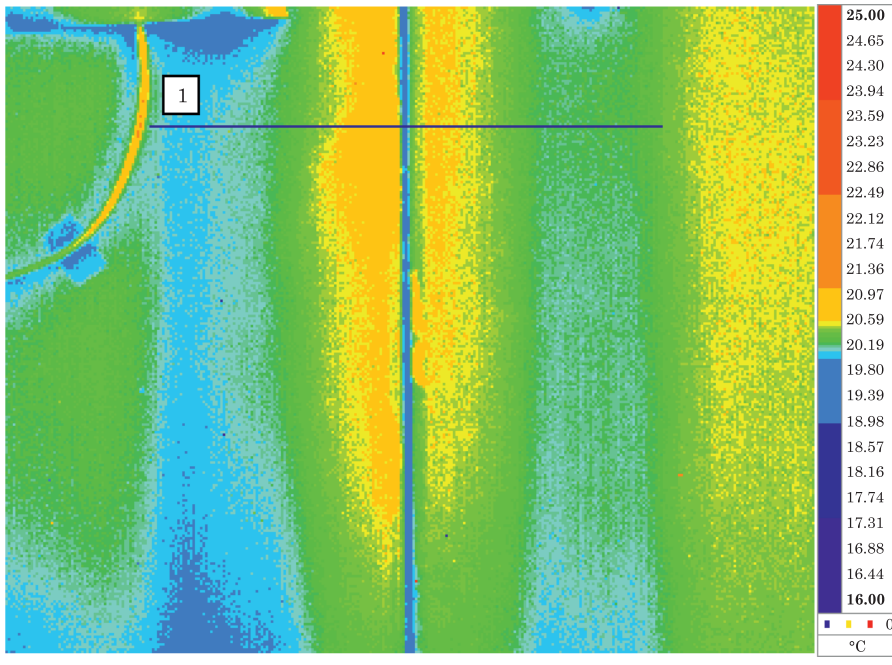

Fig. 3. Thermogram of the specimen wall with air gap in initial state at time step t = 0 min

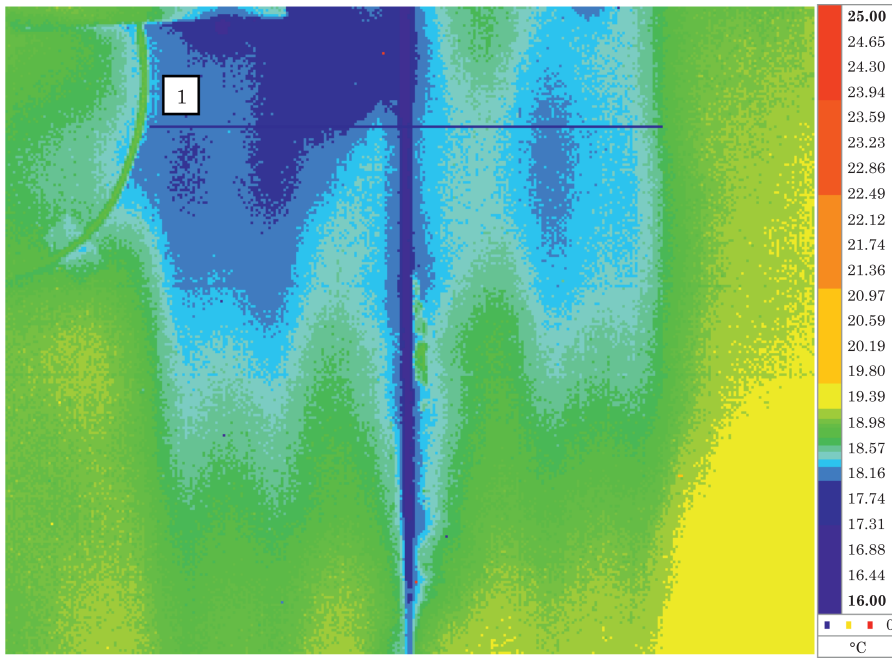

Fig. 4. Thermogram of the specimen wall with air gap, wind loaded, at time step t = 40 min

with a resolution of 320 × 256 pixels and has a thermal sensitivity of 20 mK. The camera allows to record thermal images in continuous mode. The measurements were performed in the area adjacent to the air gap. A small size of the IR specimen area (35 × 30 cm) resulted from a narrow angle of IR camera lens.

On Figure 3 there is presented a thermogram of the specimen wall in initial state, after reaching thermodynamic equilibrium before the fan has started. This state is set as a time step t = 0 min. On Figure 4 there is presented a thermogram of the specimen wall after 40 minutes of continuous fan work, it means wind speed of 3.2 m/s. This state is set as a time step t = 40 min.

The temperature curves on the graph on Figure 5 illustrate cooling of the gap and adjacent area of 20 cm width in five steps, at time 0, 10, 20, 30 and 40 minutes. The temperature profile is situated on Figures 3 and 4 as a line number 1. The temperature curves of the whole area do not show a homogeneous temperature distribution. The lowest temperature is in the middle of the gap, what is clear, but the temperature near gap is higher than further from the gap. The edges of the gap are geometric disturbances and during application of loose insulation, there may have been the obstacle which caused the

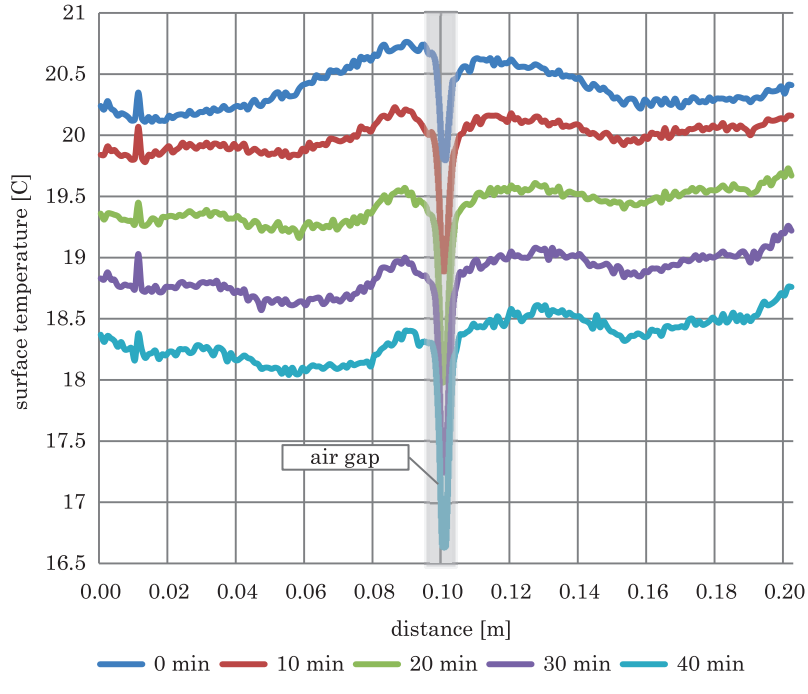

Fig. 5. Temperature curves illustrating laboratory cooling the air gap and the adjacent area in five time steps

partial occurrence of higher density of mineral wool in the wall. Such a situation is very common in practice due to quality differences in workmanship.

Simulation of thermal bridges caused by air infiltration

Thermal simulation of experiment was performed according to ISO 10211 standard using the Delphin 5.8 software based on Control Volume Method. An implementation of physical model of air filtration through a building element is constructed on parabolic partial differential diffusion – convection balance equations (1).

A simulation model was based on known characteristics of the materials examined first in Heat Flow Meter and Air Permeability Meter. Temperature values recorded in the specimen model in the climatic chamber allowed to set an initial temperature state of the simulation model. Boundary conditions and dimensions were the same as in laboratory measurements, the inner temperature 20.2°C, the outer temperature 0°C. Reynolds number calculated for the wind speed 3.2 m/s and dimensions of the air gap was Re = 722, which corresponded to laminar flow. Heat transfer resistance were calculated according to ISO 6946: R_{si} = 0.125 (m^2 · K)/W and R_{se} = 0.047 (m^2 · K)/W.

Figure 6 presents results of simulation on cross section of a part of the model. Left picture presents the temperature image of the thermal equilibrium situation before the wind load started (step t = 0 min). On the right there is the temperature image after 40 minutes of wind load (step t = 40 min).

Temperature curves on the graph on Figure 7, illustrate surface temperatures in the 20 cm wide adjacent area to the gap. The dotted lines illustrate the effect of air infiltration while the solid lines without air infiltration. The results showed on Figure 7 are presented in five steps, at time: 0, 10, 20, 30 and 40 minutes.

Discussion of the results

Laboratory investigation highlights that the lowest temperature values occur in the middle of an air gap. Even in the initial state, there is a small difference between the middle of the gap, its surrounding and the adjacent area. Temperature difference is rising while the air is flowing through the gap. More time the filtration takes, more extensive the changes of temperature are.

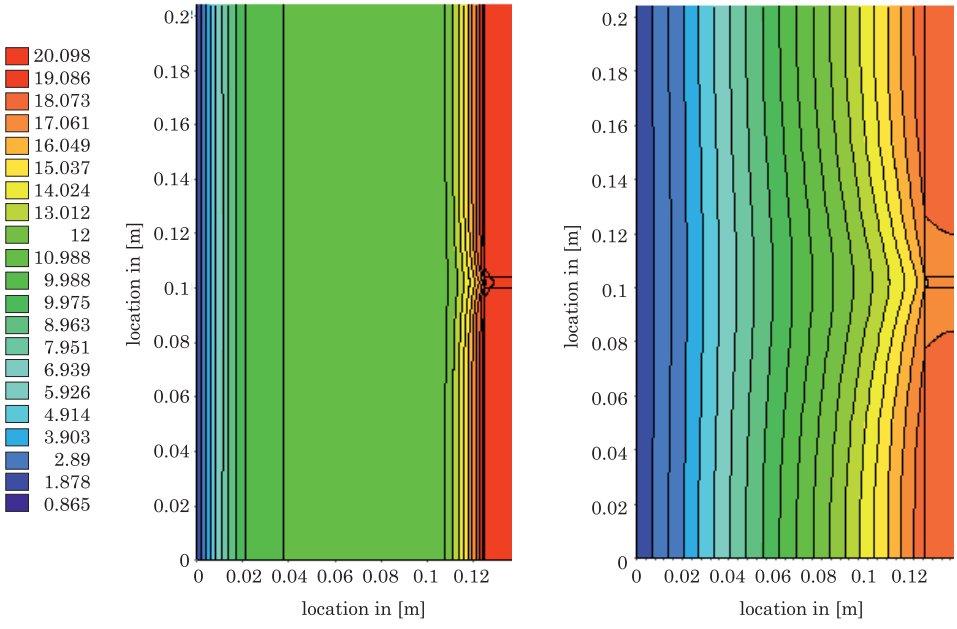

Fig. 6. The results of simulation performed to extended balance equation including air filtration, initial state on the left side and state after 40 minutes wind load on the right side

On Figures 3 and 4 it is shown, that along the gap, the temperature maps differ a little. It might be a result of non-homogeneity of materials used in laboratory investigation, especially the thermal insulation of loose mineral wool fibers is not isotropic. In order to achieve a natural situation of the partition insulated with loose mineral wool fibers in existing buildings, the thermal insulation was initially compacted manually. That may be a reason for partial occurrence of higher mineral wool density. Additionally there may be texture difference on surface of the gypsum boards.

Figures 6 and 7 illustrate results of computational simulation using Delphin software. Averaged properties of materials and dimensions used in simulation affect the symmetry of isotherms in cross section of specimen. In reality, as presented on thermograms on Fig. 3 and 4, the symmetry does not exist. Figure 5. emphasizes the range of thermal impact of air gap on its surrounding. In the initial state there were imperceptible changes in temperature fields, while after 10 minutes of infiltration, the changes are significant.

The lowest temperatures, similar in values, both in laboratory and simulation results, occurred in the middle of the gap. Differences in the area adjacent to gap may be due to imperfections in hand made specimen wall in climatic chamber.

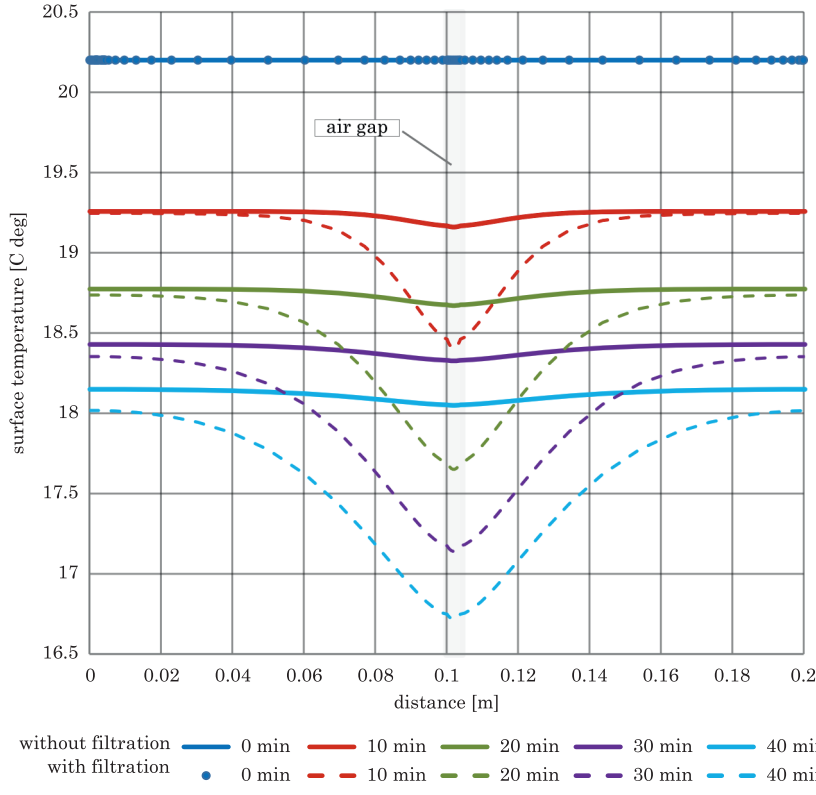

Fig. 7. Temperature curves illustrating simulation cooling the air gap and the adjacent area with and without air infiltration in five time steps

Conclusions

The implementation of laboratory study and simulation should enhance the knowledge about the impact of thermal bridges caused by air infiltration on the surface temperature adjacent to them. Although in many countries it is forbidden to construct building elements without wind and air barriers, unexpected cracks may occur everywhere. Many defects of building envelope appear after few years of using a building. In such situation, ATB should be included in heat balance calculations.

Comparison of the simulation and laboratory experiment results is positive. It means that the simulation model can be used to assess ATB values in the future. The actual work will be extended by thermal research in non-isothermal climatic chamber on other thermal insulation materials and other types of construction. There is also a need for a statistical analysis of pressure load on the heat losses in the air gaps.

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THE ROLE OF MICROFILLERS IN SHAPING THE SULPHUR CONCRETE PERFORMANCE

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K e y w o r d s: sulphur concrete, fly ash, microsilica, zeolite, compressive strength and tensile strength, abrasion.

A b s t r a c t

The article presents the research results of sulphur concrete – the material that is created at high temperature as a mixture of a sulphur binder with aggregate and microfillers. While it has very interesting properties, it is not as appreciated as it should be.

The aim of this paper is also to encourage a deeper insight into the presented material, and the use of its hidden potential. Sulphur concrete is not new a product of modern technology – it has been known for decades, but new applications are still being found. The paper focuses mostly on the impact of the microfillers used on some properties of the concrete. In the research, the microfillers used were: fly ash, microsilica and zeolite. The article presents the microfillers' influence on the growing kinetics of compressive and flexural strength and the effects of abrasion on the sulphur concrete. The lab tests were carried out after 3, 7 and 28 days. The most noticeable was the positive influence of the fly ash on concrete performance. The microfillers that influenced the material's microstructure were also presented.

Introduction

The popularity of sulphur concrete in the domestic literature is scarce, almost non-existent for such an interesting material. The concrete is made by the means of mixing (at the temperature of 135°C) sulphur binder, aggregate and in some cases several types of microfillers, which task is to modify the properties. The technology of sulphur concrete production is much more similar to asphalt concrete production than to cement concrete. Sulphur

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concrete in the building industry is not considered as a new generation product. It was applied for the first time in the first half of the 20th century and up till now has been thoroughly investigated in many articles, research studies and publications where its properties have been presented. The first mix recipe was prepared by Canadians and Americans from *the Sulphur Institute* in the 1970s. (VROOM at al 1974). The main advantage of the concrete that it gain strength very quickly. Elements made with sulphur concrete reach its designed strength after several hours but in most cases they are ready and stable after 2–3 hours, depending on the surrounding temperature. What is more, the concrete sulphur is characterised by its complete resistance to aggressive corrosive factors. Even in the 20th century, several researchers (FARAŃSKI 1999, LOOV et al. 1974, MALHOTRA 1979, ORŁOWSKI 1992) presented, that in order to obtain the composite that would be resistant to chemical corrosion, the sulphur can be successfully applied as a binder. For this reason it is perfect when applied in radioactive and toxic waste tanks, pens for animals, sewers and many other uses (KUŚ, ROGALA 2004, CZARNECKI at al 1994, ŻARKIEWICZ 1996). Its high resistance to abrasion is also an important feature. It is more resistant to rutting leading to its use in road surfaces in the United States of America (DRIVER 2012). In spite of appearances, the costs of producing a cubic meter of sulphur concrete is comparable to cement concrete. The issue of costs was investigated by Americans in 1970s when they calculated that producing concrete based on sulphur binder can be 20% cheaper when compared to traditional concrete (*it is influenced by the price of sulphur, which ranges from several US dollars to several dozens US dollars per ton depending on the location).* In Poland, the phenomenon was looked into by the company of „SIARKOPOL" company in the 1990s. Nowadays the only sulphur concrete products are made by „MARBETWIL", a company which is located in Bielsko Biała with a factory in Gliwice (FARAŃSKI 1999).

The basic aim of this research is a presentation of the strength performance and physical (density) of sulphur concrete composites with various microfillers.

The scope and methodology of the research

In the Faculty of Technical Sciences at UWM in Olsztyn has been conducted research concerning into the of sulphur concrete in different biologically or chemically aggressive environments (CIAK 2007, CIAK, HARASYMIUK 2013). The research on the modification possibilities of sulphur concrete by using different microfillers have been also carried out.

The paper presents the research results of the modified sulphur concrete with a mixture of microfillers such as: fly ash (FA) from electrofilters,

microsilica (MS) with 99.8% content of SiO_2 and zeolite (Z) with 62.1% content of SiO_2. Ground elementary sulphur with 99.98% content of sulphur (Fig. 1) was used as a binder. The last ingredient was 0/2 sand with the granulation presented on the Figure 2.

Fig. 1. Materials used in the researches: *a* - sulphur, *b* – fly ash, *c* – microsilica, *d* – zeolite
Source: Fig. *b* – Photographs taken by D. JANKOWSKI

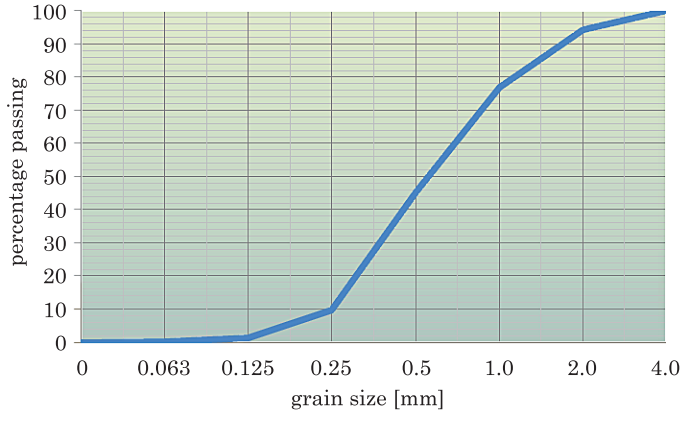

Fig. 2. Granulation of sand used in the research

The percentage shares of particular ingredients of the sulphur concrete mix which is presented in figure 3 was established by the following trials.

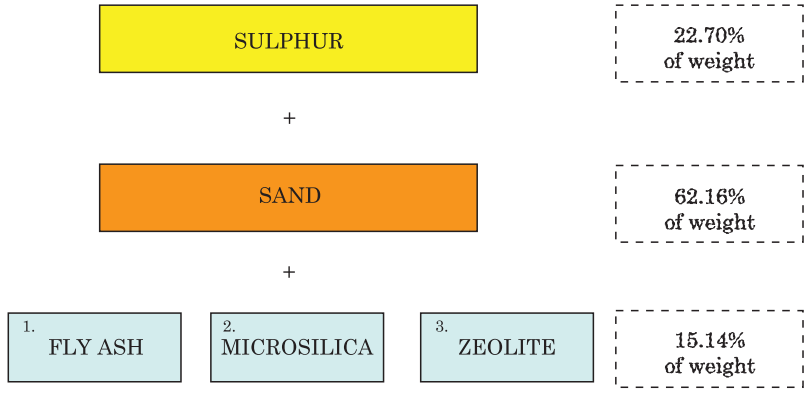

Fig. 3. Composition of sulphur concrete

Samples (100×100×100 mm and 40×40×160 mm) were prepared in an automatic agitator (Fig. 4) where melted sulphur was mixed with previously heated ingredients (sand and one of the microfillers). The temperature of the mix was 130-140°C. After obtaining uniform, smooth consistency, the mix was poured into casts (also previously heated to the proper temperature), then it is thickened with vibrations and finally stripped after several minutes (Fig. 4).

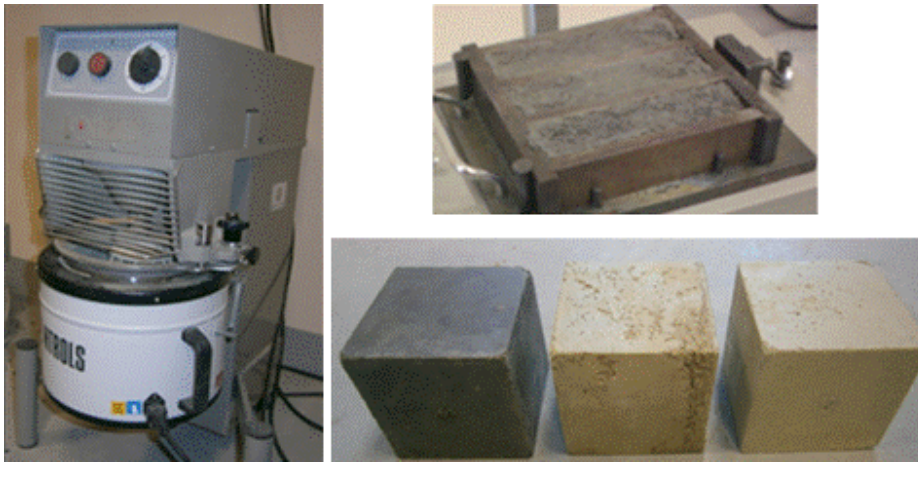

Fig. 4. Agitator for bitumen used in the research (on the left); Trigeminal cast filled with the sulphur concrete mix and a sample (100×100×100 mm) of the sulphur concrete with a mixture of fly ash, microsilica and zeolite (on the right)

Source: Photograph taken by D. JANKOWSKI

Fig. 5. Strength press ADVANTEST Controls
Source: Photograph taken by D. KOZŁOWSKI

Prepared samples were tested for their mechanical and physical properties. Flexural and compressive strengths were carried out in accordance with PN EN 196-1 in the strength press ADVANTEST 9 Controls (Fig. 5). The results are discussed below.

Abrasion resistance was tested on a Boehme abrasion testing machine (Fig. 6) according to the guidelines of PN-EN 14157:2005 standard. Cubic samples of sulphur concrete with the dimension of ±71mm were subjected to 16 rotary cycles (22 rotations each).

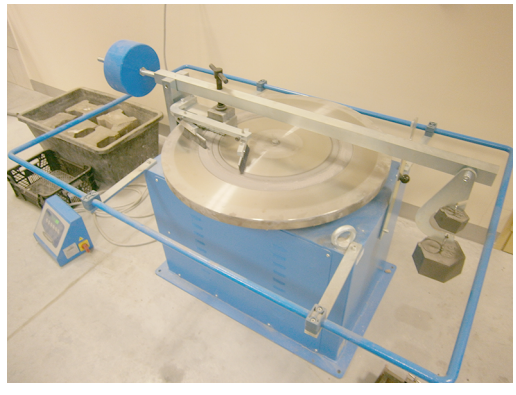

Fig. 6. Boehme abrasion testing machine
Source: Photograph taken by D. KOZŁOWSKI

Results

The analysis of strength tests after 28 days (Fig. 7) shows that the best results were achieved with samples, where fly ash (FA) was used as the microfiller. The use of microsilica and zeolite decreased the compressive and

flexural strength. In case of flexural strength the decreases were about 45% (MS) and 30% (Z) and respectively 30% (MS) and 10% (Z) in the case of compressive strength, comparing them to the results achieved on the fly ash (FA) samples.

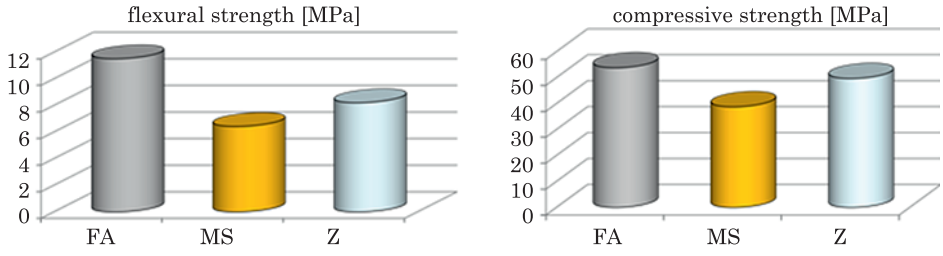

Fig 7. Tests results of the sulphur concrete samples with the micro fillers: fly ash (FA), microsilica (MS) and zeolite (Z)

In both compressive strength and the flexural strength tests results far exceeded the values obtained by standard concrete. It is especially noticeable in the flexural strength where the results can prove a different destruction mechanism. Concrete based on sulphur can be easily classified as fragile material as proved by the strength tests. Fragility which is described as a ratio of compressive strength to tensile strength in bending (Tab. 1), increases after the application of microsilica (MS) or zeolite (Z). It can evidence of decreased consistency of these fillers with the matrix – the sulphur binder.

Table 1

Average results of strength tests of the sulphur concrete samples

Type of a sample	Strength		Compressive strength /flexural strength
	compressive	flexural	
	MPa	MPa	
FA	53.78	11.51	4.67
MS	38.73	6.42	6.03
Z	49.64	8.20	6.05

As predicted, the apparent density (PN EN 12390-7) of the variations tested of sulphur concrete are quite similar (Tab. 2).

Table 2

Apparent density of the sulphur concrete

Concrete type	Apparent density [g/cm^3]
Sulphur concrete with fly ash	2.182
Sulphur concrete with microsilica	2.196
Sulphur concrete with zeolite	2.161

The summary of the Boehme abrasion tests results are presented in table 3. In this case, the mixture of fly ash still gave better results than microsilica (MS) and zeolite (Z).

Table 3

Abrasion resistance of the sulphur concrete after the Boehme test

Type and number of a sample		Mass before test m_i [g]	Mass after test m_f [g]	Loss of mass Δm [g]	Apparent density ρ_b [g/mm^3]	Change in the volume of a sample [mm^3]	Average change of the volume of a sample ΔV_{av} [mm^3]	Average loss of the height of a sample Δh_{av} [mm]
With fly ash	1	714.0	698.3	15.7	0.0021815	7,196.88	8,709.6	1.73
	2	715.8	692.3	23.5	0.0021815	10,772.4		
	3	730.0	712.8	17.8	0.0021815	81,59.52		
With microsilic	4	743.0	720.5	22.5	0.002196	10,245.90	10,898.6	2.16
	5	721.08	695.6	26.2	0.002196	11,930.78		
	6	729.07	706.6	23.1	0.002196	10,519.13		
With zeolite	7	718.8	701.6	17.2	0.0021609	7,959.65	8,530.4	1.69
	8	724.1	706.8	17.3	0.0021609	8,005.92		
	9	711.0	690.2	20.8	0.0021609	9,625.62		

Summary

The research proved the good strength performance of sulphur concrete. The results of 40÷50 MPa (compressive strength) and 6÷11 MPa (flexural strength) are comparable to the results of higher class concrete. What is more, low abrasion (1.6÷2.2 mm depending on used microfiller) shows that sulphur concrete and its products can easily compete with products made of standard or asphalt concrete. The additional advantage of sulphur concrete is the relatively simple technology of its production (similar to the asphalt concrete technology) and time span needed for the full maturity of the concrete. The tests also prove the effectiveness of fly ash application as microfillers. This article presents the results of the research, which are a part of a wider research program that aims at proving the necessity of a modification of sulphur concrete and of promoting its usage as a replacement for cement concrete and asphalt concrete.

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USAGE OF LIDAR DATA IN PLANNING OF WIND TURBINES LOCATION

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K e y w o r d s: wind turbine, LIDAR, information system, geophysics, georadar.

A b s t r a c t

The aim of this paper is to confirm the thesis that by the usage of laser scanning methods it is possible to find a link confirming the characteristics of swampy land on which the specific building projects are supposed to be carried, as well as their requirements in high accuracy of location and the stability and durability of the substrate. Visible to the naked eye, regular depressions in the ground may foretell the places of underground space, created or influenced by the flow of water or due to geological structures, characterizing the substrate as inconsistent. These spaces seriously affect the possibility of placing wind turbines. By using LIDAR high correlation is visible between the characteristics of the terrain model and the location of underground geological spaces that could endanger the constructions that will be formed in the area. While the construction is being built the ground emphasizes so much that wrong location can simply cause the collapse of the structure. The results were supported with geophysical researches, using three methods: ERT – electrical resistivity tomography, GPR – ground penetrating radar, and the seismic method.

Photogrammetry and information systems

Due to the rapid development of remote methods of obtaining data of the area and the environment from the aerial and satellite altitude, and also continuing development of digital technologies of their processing, integration and visualization, possibilities of generating the various sets of results on the basis of photogrammetric and remote sensing are still growing. They are more and more useful for creating various databases and information systems, thereby causing a steady growth of range of their users. A completely new situation arose upon the occurrence of air laser scanning methods with very

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high resolution. In terms of basic performance parameters, these methods slowly but steadily and quite effectively find the right place in market applications (KURCZYŃSKI, WOLNIEWICZ 2002, 2005, KURCZYŃSKI 2005, dish, Authorized Retailer, on line: http://www.spaceimaging.com/). LIDAR data, obtained on the basis of the results of the scan area provide data with a very new standard. It;s rich and actual information of the areas, may be a valuable component of information systems, and due to their combination of geophysical methods can create an interdisciplinary space for their application. An example of such of use is the collection of data about the terrain model, which, together with geophysical data, provide information and evidence of the existence of a variety of geological structures, and thus the heterogeneous characteristics of the land. This in turn gives an opportunity to create geo-referenced databases that implied in GIS applications allow you to conduct multivariate and multi-criteria statistical and space analysis.

LIDAR data as a support of wind turbines localization

LIDAR – Light Detection And Ranging, as the innovative measurement technology, is carrying its powerful possibilities waiting for the appropriate application usage, due to the creativity of human thought – approaching year by year the new horizon of different solutions.

Using LIDAR data we can clearly see a high correlation between the characteristics of the terrain model and the location of underground geological space that could endanger the constructions that are formed in the specific area. It;s very common on the wetlands where the ground surrounding them is not stable. Terrains under the construction of wind farms (resp. individual turbines) affecting huge ground pressure, so choosing the wrong location our structure may simply collapse. Therefore, the construction process of these expensive types of investment must be preceded by an appropriate diagnosis of the site, which excludes the danger of moving and unstable ground.

In the present case, due to the laser scanning it is possible to find a link confirming muddy and treacherous characteristics of the land on which specific projects are going to be done with high accuracy location requirements as well as the stability and durability of the ground. The first step of „recognition" of such the area is pre-acquainting with the project, completing the analysis of geological maps and determine the characteristics of the land. Additionally, due to the LIDAR data for the surface on which the wind turbines will be built, you can pre-specify (and exclude from the construction process) areas at a high risk, eg. excessive subsidence.

The study assumes that visible to the naked eye, regular depressions in the ground can foretell the location of underground space, created or influenced by the flow of water, or due to geological structures characterizing the ground as inconsistent. The confirmation of the assumptions are geophysical surveys of land using three methods:

– Electrical Resistivity Tomography – ERT
– GPR method – GPR,
– Seismic method.

Coordinates research areas were determined using GPS technology, with-Trimble TDS controller, using in some cases the Trimble S6 Total station with CU controller. To develop the test results mainly AutoCAD, Surfer, and Seisimager software were used.

Survey data

Nowadays, LIDAR information are gathered mainly with scanning. The most often several detectors „line by line" scan the area under consideration, in the same way as our home scanner built into the printer simple scans our documents. As the result a point cloud gives information about the topography of the terrain, which is also the most common reason to use scanning technology. Analysis of LIDAR signal, however reflecting from various surfaces, allows us more. Special raw data processing algorithms are able to determine the physical properties of these surfaces, giving for example their relative roughness or their movement. When the surface is covered with objects partially transparent for the laser beam (eg. vegetation or snow) it can also gather information about their structure. The signal emitted during the measurement is partially disturbed by the atmosphere – in connection with the LIDAR data you can also obtain information on its characteristics. LIDAR has already found its place in optimizing the use of wind energy with for example built by engineers from Stuttgart control system that measures wind speed and direction before it reaches the turbine blades (The business of photonics. Optics.org, on line: http://optics.org/news/3/6/16).

The base for correct interpretation of the obtained measurement data is the clarity of the resulting material. The raw data without proper processing cannot meet its role, if you don;t choose (depending on the destination to which they serve) adequate accuracy – the obtained image clarity. In this work it was necessary to consider each point obtained with LIDAR technology, so the capacity of data required equipment with high computing power. For this specific case an access to pre-processed 24 files in *.xyz was obtained, the surface of which was between 8 and 100 hectares, the total area of land covered

with LIDAR was about 2,276 ha. On the surface were collected more than 91 million laser points, of which nearly 59 million are points contained valuable information. Selection of a suitable GRID resolution was very important in the process of interpretation. Note, however, that the disadvantage of the selected grid with higher resolution is multiplied with the size of files being processed, and the extended time required to calculate the data. For the purposes of accuracy of interpretation in this project there was established GRID resolution of 0.5×0.5 m. Initial processing of one file with the specified accuracy using the „Surfer" application took about 15 minutes. The end result of developed mosaic is given in Figure 1.

In a further stage the LIDAR data were processed using the „Surfer" application. It made it possible to isolate changes in topography, providing the potential risks of instability and incoherence of the soil (Fig. 2). Red lines that marked running down the slope longitudinal gullies as a result of flowing watercourses. Thus allowed to identify and separate on the image potential areas that are exposed to specific ground incoherence, as well as defining the location and directions of measuring lines for which it is necessary to conduct additional geophysical surveys.

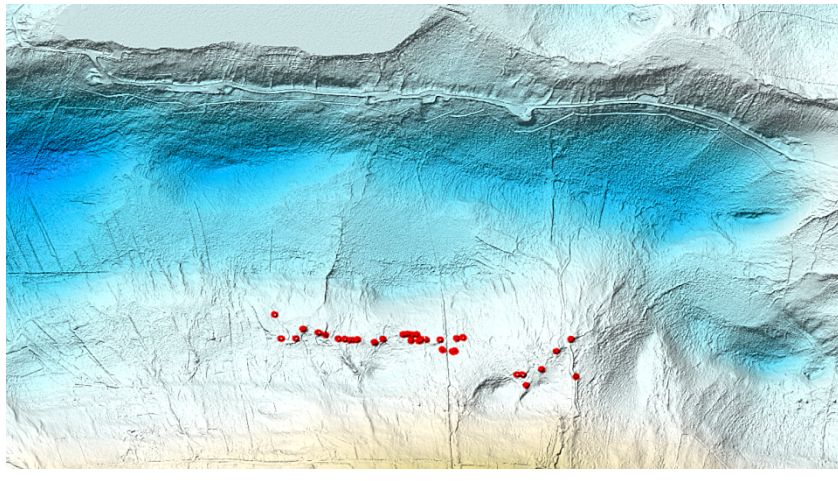

Fig. 1. The GRID of 0.5 m size with the presentation of basins (red); mosaics made using „Surfer"

Photogrammetry for many years has been providing flight data, but in spite of technological progress in this field (both the hardware and application), followed by the recording of data at very high resolution photogrammetric aerial photos are not able to replace the LIDAR data in terms of detail and the possibility of manipulation in order to improve the conditions of interpretation. For comparative purposes, the following figure (Fig. 3) contains the image

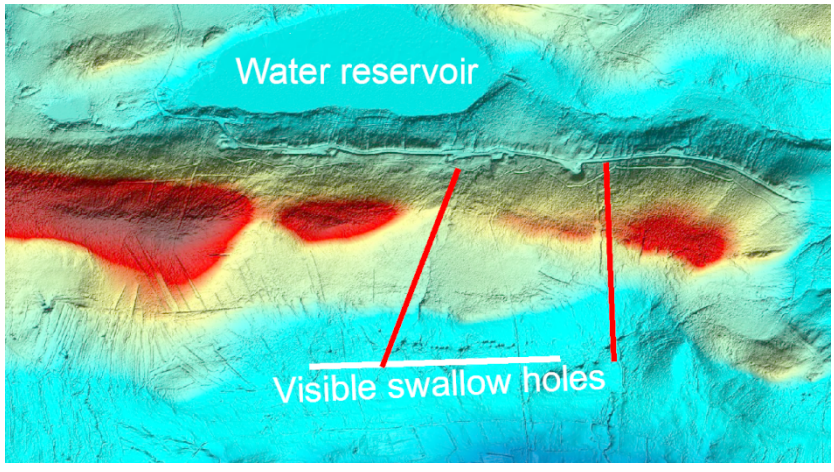

Fig. 2. Processed LIDAR data using „Surfer" with marked changes in topography indicating the dangers

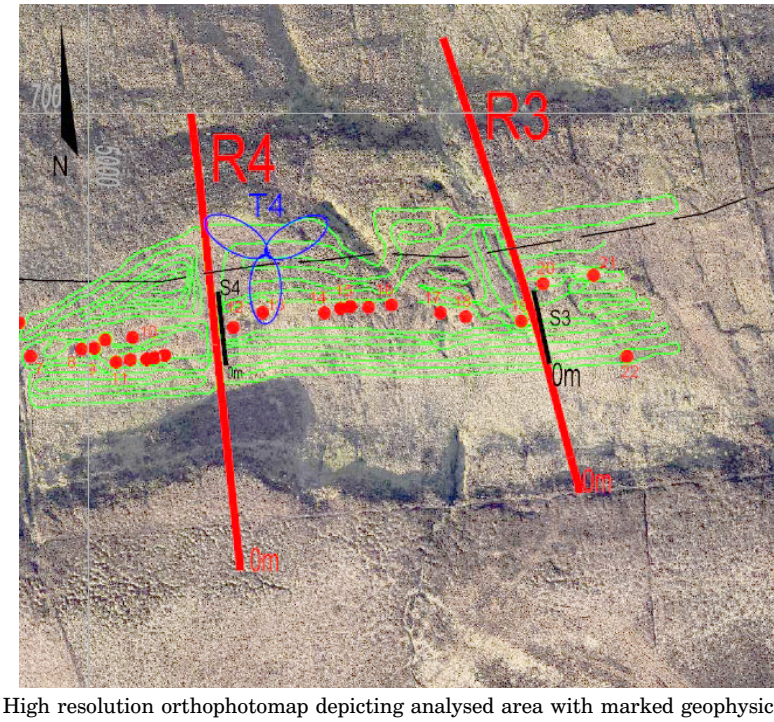

Fig. 3. High resolution orthophotomap depicting analysed area with marked geophysical survey

of Orthophotomap for the same part of land which proves of LIDAR technology advantage over the traditional methods of observation. The following image despite its high resolution shows how much it can be complicated for interpre-

tation and preparation of data with using inappropriate methods and tools, despite their extremely high costs.

At the end it should be highlighted that during long-term investments building lands are in most cases left as recycle, and vegetation areas from time to time are instantly covering terrains increasing the risk of error while planning the location of various types of engineering structures. LIDAR in all its complexity is not, after all nothing more than a technology of distance measurement using laser light. It therefore does not penetrate „into the depths" of the earth, so the assumption presented in this study need to be confirmed by methods that allow penetration inside the structure, about which LIDAR has „no idea". However, extensive areas (here: more than 2000 ha) and difficult to diagnose, even only because of the characteristics of the terrain or its size can be pre-analyzed using LIDAR technology, also by observing and analyzing specific changes in topography.

Geophysical land investigation as a complement of LIDAR data

Based on data obtained from laser scanning, there has been selected some methods of measurement of land that should confirm suspicions of the qualitative content and carrying capacity of land for wind turbine constructions that will be built. Finding the most appropriate methodology is the basis for all research, primarily to determine exactly what type of methodology should be taken into account for economic reasons, as well as external factors (accuracy, size of objects etc.). After an appropriate analysis an elimination of methods can be done, execution of which would be impossible to achieve, selecting those for which the previously mentioned factors are not a problem. The variety of measurement methods allows to analyze data at the circumstances, which for many measurement methods are unfavorable. In addition, studies should be properly interpreted, taking into account the lithology of the whole (surrounding the test area) area – reading, among others, the contents of geological maps.

Seismic refraction profiling confirmed the depth of the top of a rock on the basis of an increase in the speed of seismic waves. In conjunction with electrical resistivity tomography could be interpreted as variations in the speed of seismic change in the type of overburden (bedrock). Electric Resistivity Tomography (ERT) has allowed to define changes in the type of bedrock and depth to the upper layer of rocks along the right profiles that had up to 475 m in length. ERT profiles also showed maps of sharp changes in the topography of the bedrock, and these in turn pictured lithology of the same substrate.

Normally ERT is used to search for structures that could be a source of water supply for larger subsurface water intakes. In this case, attempt was to establish the zone of occurrence of the aquifers, as well as sudden changes in the structure of the surface (STYLES 2012).

ERT is currently widely used (relative to the other geoelectrical methods) at least for the sake of a relatively low amount of time spent on measurement. Real-time measuring apparatus allows for error analysis and quality control – using company equipment ABEM (ABEM France, on line: http://www.abemfrance.eu) is also possible to carry out preliminary analysis and derive generalized conclusions to the properties of the object, interpreting (by viewing the display device) to constantly updated picture, which is one of the results of measurements.

Fig. 4. Installation of one of the lines of electrical resistivity tomography profile

Ground Penetrating Radar (GPR) works by sending radio waves into the ground and measuring the time of the reflected wave. Reflections occur where different characteristics of the material are present. For example, the peat base is usually surrounded by materials with significantly different properties. This in turn generates a strong signal at the base of the peat allowing accurate measurements of it;s thickness. GPR technique is widely used, among others, to determine the thickness of peat bogs both in high places, as well as those laid down (Fig. 5).

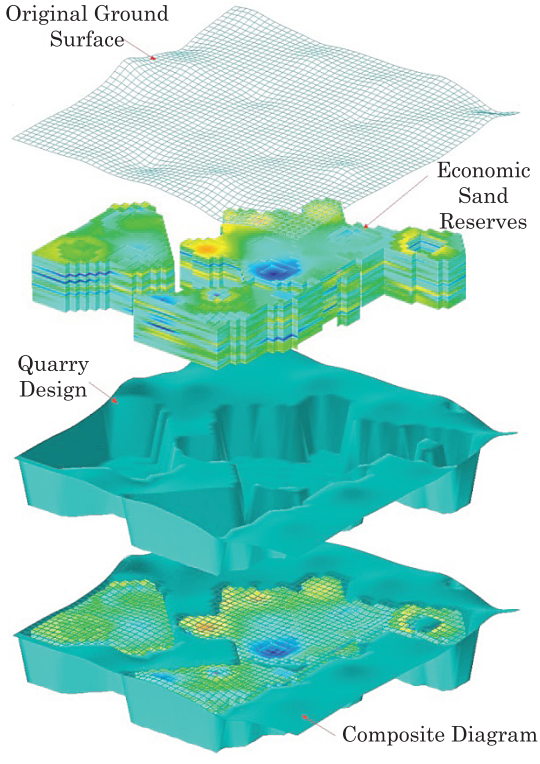

Fig. 5. Modeling portion of land obtained using Rockworks software
Source: RockWWare. Earth Science and GIS Software, on line: www.rockware.com

Weather has a very little influence on results of Electric Resistivity Tomography or Ground Penetrating Radar. Seismic refraction on the other hand is one of the methods that need a lot of attention in regards of conditions in which it is been gathered. Wind, drops of rain – not even mentioning hailstones has a negative effect on the quality of collected data. Image quality on screen connected to seismograph becomes uncertain because of the noise created by poor weather conditions.

The sum of all the foregoing considerations, creates very close to reality interpretation showing the actual state of the studied area. It happens that the projects also include in its specification drilling carried out by specialized institutions – which confirm the values obtained from geophysical surveys. In this design, such a solution also occurred. Any ambiguity of the rule is clarified carrying out additional measurements, often using the methods so far in the research process is not used and the description of which in this paper is not included.

Results

The primary objective of the present study was to attempt to integrate two completely different technologies metering to develop an effective method for assessing the soil properties, in terms of its qualitative composition in different geological layers, and consequently the detection of its potential heterogeneity (instability). Collected measurement data and developed material largely contributed to the effective assessment of the soil and its physicochemical composition, which in turn allowed to determine the right places for location of future engineering structures. In the present case, this was accomplished by using LIDAR data and geophysical investigations. The collected information about thickness of peat in area of study (as one of the main factors destabilizing the ground) has shown that there is no clear correlation between the thickness and development of sinkholes in the area of study. In the area of most sinkholes thickness of the peat is less than 1 m. If the subsidence of peat would be the main reason for the development of sinkholes greater thickness of peat surrounding majority of them would be expected (Fig. 6).

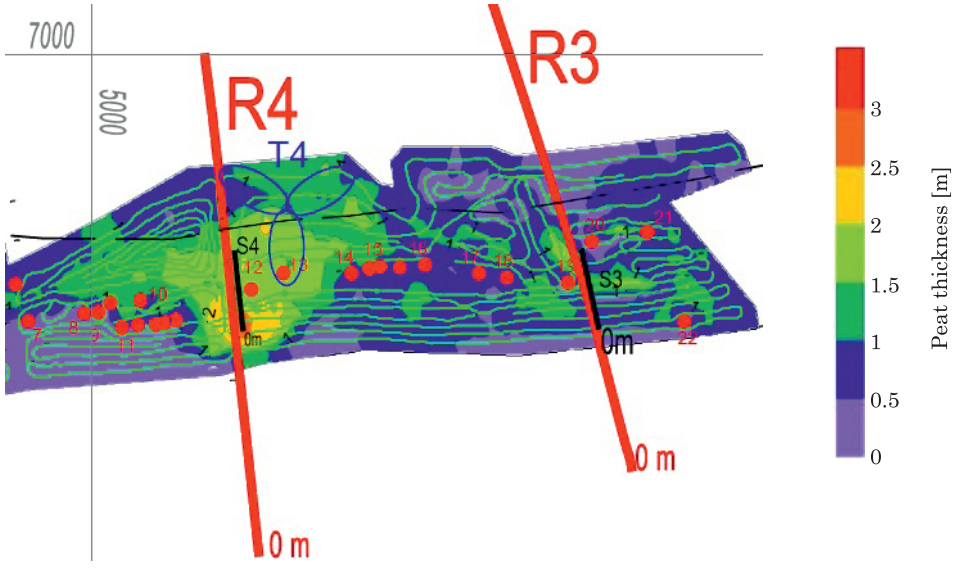

Fig. 6. Sketch showing the thickness of the peat in the analyzed area

Geological map of the study area also indicates that sinkholes were formed on limestone formations. These in turn are formed when water flows from the surface of impermeable bedrock area prone to chemical dissolution. Water is

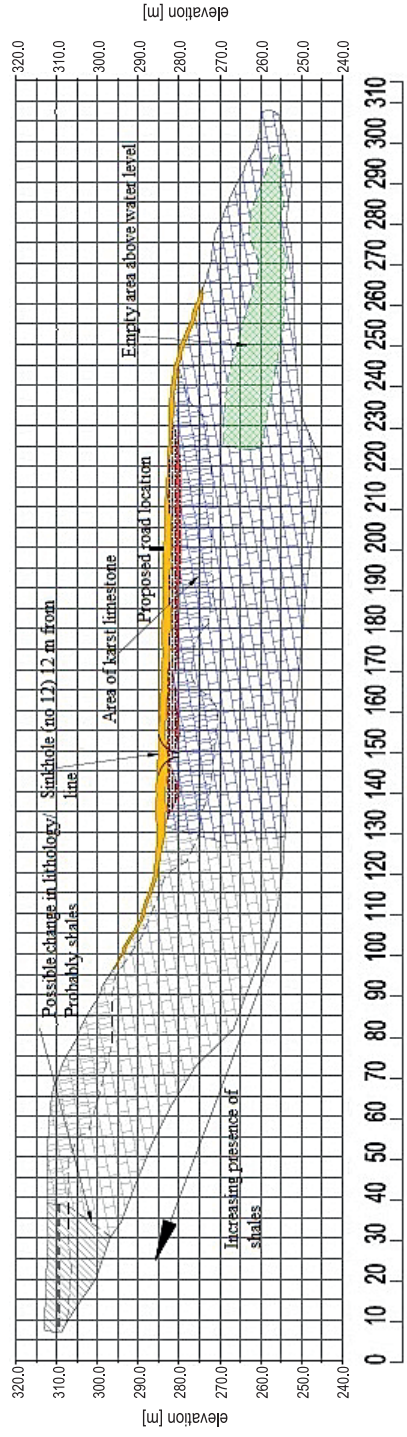

Fig. 7. Sketch showing the general flow path surface and subsurface detected by the ERT method

a material that rinse and stratify ground, significantly worsening its physicochemical properties. The analyzed area water flows from the surface impermeable shales and clays to the surface of the limestone – prone to dissolution. The boundary between the impermeable shale and limestone is a major factor in the formation of sinkholes. Therefore it can be assumed that this flow of surface water across the border of slate and limestone causes the formation of sinkholes in the study area, thus contributing significantly to the deterioration of ground conditions (Fig. 7).

Conclusion

To summarize the above development we should be fully aware of the stress that modern methods of data collection and interdisciplinary way of their analysis made possible to achieve effects, which developing few years ago would have been impossible. As shown in the example of research, it was possible to detect potential threats of instability and heterogeneity of soil using LIDAR data with the help of geophysical investigations. Effects of work that can be seen in the attached sketches, and what is also attached to this paper are the results of the discussions of many people, including geophysicists, geologists and surveyors.

Despite this, it is only a preliminary step of indicating the necessity of further work that will confirm or complement the captured material. Whereas, however, in the subconscious over documented facts, and a high degree of detail of the available data in relation to the information received by other methods, can be expressed conviction advantage of these unambiguous young technology. It should be remembered, however, that the factors that influence the overall results of the study is more, like every interpreter (which is another important factor in data processing) in a slightly different way is able to interpret obtained using LIDAR technology data. We express the hope that the results obtained will serve as a contribution to further research and analysis.

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PROFESSIONAL PROFILES AND PERSONALITY TRAITS TOWARDS SOCIAL NETWORK TEAM BUILDING

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K e y w o r d s: business intelligence, social network team building, personality trait.

A b s t r a c t

Today's increasing hurriedness in our way of life along with technology advances demand from businesses to react always in a faster mode, while maintaining or, better yet, improving the quality of their products and services. Towards that objective, businesses can gain benefits by employing redefined team-building processes through which teams will be generated in a more cohesive and efficient manner. Aiming at forming productive and effective teams, we present PROTEAS, a framework where professional profiles and personality traits are both taken into account in the team-building process. The professional portrait of users is drawn from their LinkedIn accounts, while hints for their personality are obtained by a well-defined questionnaire based on the Big Five Factor Model. The significance of personality is substantiated by recent research work where it has been proven that personality traits can play a vital role in group dynamics. Motivated by the latter, PROTEAS defines a series of variables where characteristics of team members (e.g. skills, education) are combined with personality traits towards identifying candidate teams. All candidates are evaluated via a weight-based algorithm which calculates pair-wise similarities among teams' members and ranks the teams accordingly at the end. To assess the effectiveness of PROTEAS an academic setting has been chosen and through the experimentation a number of interesting observations occurred which are analogous to those of similar researches, confirming the significance of personality and professional compatibility between team members.

Introduction

As the years go by businesses aim to create new products and services, ever faster, while maintaining or, better yet, improving quality. In order to cope with the new volume of demand that defines the current business world, they have to utilize every possible „weapon" in their arsenal. One way to do so is to reassess one of the first and most important steps in new product development: **Team Building**.

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Teams are more often than not created based on the technical requirements of a given task, project or product. As a result, team members are selected because they have the necessary skills, experience or expertise. Research has indicated, however, that personality can play a significant role in group dynamics (NEUMAN, WRIGHT 1999, THOMS et al. 1996). It is suggested that the cohesion of the group and the right match of its members' personalities also contribute positively to the successfulness of a team (LEPINE et al. 2011).

At the same time, we have witnessed an exponential increase in the use of social media, especially during the last decade. Not only do we encounter a plethora of them, but new types also emerge, such as social networks with a business direction.

These observations instigated our motivation for this paper, which can be summed up in two succinct points:

– Personality traits may contribute to team cohesion and good interpersonal relations, which in turn lead to the greater team efficiency (see Related Work).

– Social media have become very popular, resulting in a world rich with professional-related information.

We would like, for these reasons, to approach the subject of team building under a different light, and provide a way for all these new criteria to be included in the team formation process, so as to create more efficient and productive teams with greater cohesion. This will be the result of the combination of two factors: team members' professional profile and their personality traits.

As a result of our work PROTEAS has been created, a framework combining users' professional profiles acquired through LinkedIn, a business-oriented social network, as well as their personality characteristics, based on the Big Five Factor Model, which are acquired through a personality test we provide. A rough outline of this procedure is presented in Figure 1. PROTEAS starts by

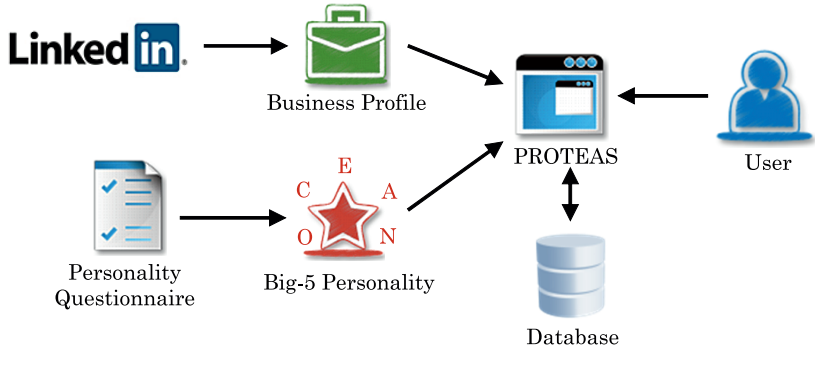

Fig. 1. Collection of user information

creating candidate teams with similar users based on their professional profiles and then, as a second-stage process, those candidates are evaluated in terms of the personality parameters of their members.

The remainder of this paper is structured as follows: In Section 2 we present some fundamental ideas, which deal with personality and work effectiveness. The theory behind our framework is described in Section 3. Section 4 presents the results of our experiments. Lastly, in Section 5 we conclude and discuss some possible future directions.

Preliminaries and Related Work

In this section we provide both a brief overview of the building blocks of our framework and present a number of representative studies regarding team building.

PROTEAS Fundamental Concepts

The presented framework is comprised of users' professional profiles and personalities, as well as teams and team forming.

– A professional profile is a collection of information mainly regarding a person's working experience and also other qualifications, such as the skills a person has acquired, his academic background, publications, awards and honors.

– In recent years, a new theory about personality is agreed upon by most of the modern personality psychologists: The Big Five Factor Model (JOHN, SRIVASTAVA 1999), whereby each person's personality can be described as a combination of five major traits, or dimensions:

- **Openness to Experience** or **Intellect** is a person's curiosity, imagination, creativity, un-conditionality, level of realism, and resistance to change.
- **Conscientiousness** is linked with organization skills, work ethic, self-discipline and goal realization with persistence and thorough planning.
- **Extraversion** is the level of sociability and enthusiasm, and is in a way a measure of the intensity of the person's interaction with others.
- **Agreeableness** indicates how kind, altruistic and friendly is one person towards others, as well as their level of cooperation or sense of competition.
- **Neuroticism** or **Emotional Stability** indicates whether a person is tranquil and calm or irritable, emotionally unstable or moody.

– A team is a group of people working interdependently, with a full set of complementary skills, required to successfully carry through a given task or

project, for which they are mutually accountable (KATZENBACH, SMITH 1992). In most cases, team members are either chosen because they have the necessary skills or work experience, or because the members have some degree of previous acquaintance (ALDRICH, KIM 2007).

Related Work

Traditional team building criteria are those concerning a team's demographics or members' skill-set. Team building processes of this kind are trivial and widely known. For example, the use of a design structure matrix is used along with sequencing and grouping algorithms (DUNBING, ZHENG 2000, EPPINGER, WHITNEY 1994). In addition, HLAOITTINUN et al. (2007, 2008) propose an array-based clustering process which mostly takes into account the team members' competency for a specific task. A matrix is created denoting each member's competency for the parameters of the task at hand. Then, a clustering algorithm is applied, and for each possible cluster a performance indicator is computed.

We would also like to focus on the role of personality on work efficiency and explore other factors that benefit a team's effectiveness. The study of Personality started in the 50's and the definition of the Five-Factor Model soon followed (JOHN, SRIVASTAVA 1999). A great portion of research has been made in order to establish a connection between personality traits and job efficiency. Conscientiousness has been regularly found to be a valid predictor of job performance, either in general (HURTZ, DONOVAN 2000) or in specific job families (BARRICK, MOUNT 1991). Openness to Experience may validly predict performance in Management and jobs involving Customer Service (HURTZ, DONOVAN 2000). Extraversion is a valid predictor of job performance for occupations that have social aspects (KICHUK, WIESNER 1997). Neuroticism and Agreeableness have showed relatively low correlations (Barrick and Mount, 1991). On a team setting, Conscientiousness along with Agreeableness seem to be highly significant as working in a team involves communication and social interaction (LEPINE et al. 2011, NEUMAN, WRIGHT 1999). Nevertheless, there are cases where having high Agreeableness levels could be detrimental; an individual challenging the ideas of the team could lead to reassessing the problem and producing better results (THOMS et al. 1996), as we have also encountered in our study. Emotional Stability is believed to be positively correlated with team performance (THOMS et al. 1996). The roles of Extraversion and Openness to Experience are not well defined in a team setting (KICHUK, WIESNER 1997).

Apart from personality traits, demographics (e.g. age, gender) seem to have no relation whatsoever, for the successfulness of a team. For instance, KICHUK, WIESNER (1997), found no significant difference between teams regarding the number of female members participating. Also, REAGANS et al. (2004) com-

pared the efficiency between teams based on demographics and teams based on the social connections of its members and found no sign that the former are more productive.

We observe that team efficiency and cohesion is attributed to different factors, and studies have been carried out for each one of them. We believe that all these factors are important in relation to team effectiveness, and we thus try to utilize them in our framework, as presented in the following section.

PROTEAS: „Automated generation of PROfessional TEAms in Social networks"

In this section we present a solution to the problem of creating efficient teams, in the form of PROTEAS, our team building framework, which runs as a web application, written in PHP and storing data in a MySQL database. The professional profile of users is drawn from their LinkedIn accounts and through a questionnaire their personality outline can be assessed, according to the Big Five Factor Model. For this purpose, we selected IPIP[1], which is a public domain list of personality items, and we created a questionnaire containing 50 items. The test is a typical 5-point Likert-type scale, where each item can be answered with one of the following options: (i) Strongly disagree, (ii) Disagree, (iii) Neither disagree nor agree, (iv) Agree or (v) Strongly agree.

Teams are created by first setting the desired parameters: team size, users' skills, languages spoken, industries they belong to, geographic location, academic background, and the personality parameters, where each trait is expressed as a relative value (low, medium, high). Then, all possible team combinations are calculated and a process of ranking is employed, so as to propose the best team available. For this purpose, we created a metric in order to compare the available teams.

Similarity Measures

To calculate the similarity between two users, we provide a set of different similarity measures. The available similarity measures are: Skills, languages, industries, location, and education, which we have extracted from users' professional profiles and LinkedIn. The basis for our formulae is the Overlap Coefficient (SIMPSON 1960), which in turn is based on the Jaccard Index (JACCARD 1901).

Skill-based Similarity. Users can define a set of skills that they have acquired. To find the similarity between two users' skills, the overlap coefficient is used:

[1] International Personality Item Pool: http://ipip.ori.org/

$$\text{Sim}_{\text{skill}}(A,B) = \frac{|\text{Skills}(A) \cap \text{Slills}(B)|}{\min(|\text{Skills}(A)|, |\text{Skills}(B)|)} \quad (1)$$

Language-based Similarity. In defining a spoken language users also set the level of their proficiency, with 1 being the lowest and 5 the highest. We thus use an altered version of the Overlap Coefficient. We first define the language proficiency range as maxRate – minRate + 1 = 5. The value between two languages is:

$$\text{value}(\text{Lang}(A), \text{Lang}(B)) = \frac{range - diff}{range} = \frac{5 - diff}{5} \quad (2)$$

where $diff = |\text{rate}(\text{Lang}(A)) - \text{rate}(\text{Lang}(B))|$. The final similarity formula is:

$$\text{Sim}_{\text{lang}}(A,B) = \frac{\Sigma_{i,j}(\text{value}(\text{Lang}_i(A), \text{Lang}_j(B)))}{\min(|\text{Langs}(A)|, |\text{Langs}(B)|)} \quad (3)$$

where $\text{Lang}_i(A) = \text{Lang}_j(B)$, $0 < i \leq |\text{Langs}(A)|$, and $0 \leq j \leq |\text{Langs}(B)|$.

Industry-based Similarity. LinkedIn defines 147 different industries, which can belong to one, two, or three of 17 general groups. Users may fill in an industry that they believe that describes them, which we define as the main industry. In addition, secondary industries can be assessed from current or past jobs. Comparing two industries we can find them being the same, belonging to the same general group or groups, belonging to some of their respective groups, or belonging to different groups entirely. Sample industries are presented in Figure 2. For each pair, we calculate the Overlap Coefficient of

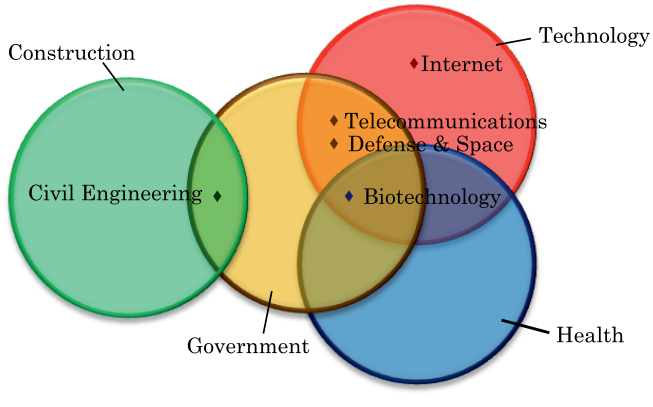

Fig. 2. Sample industries and their corresponding groups

their corresponding groups. We also define the probability of the event that each of these cases happens, and the corresponding reward as 1 – probability(event).

We define the score between two industries as:

$$\text{score}(\text{Ind}(A), \text{Ind}(B) = \begin{cases} 1, & \text{Ind}(A) = \text{Ind}(B) \\ \text{Over. Coeff} \cdot \text{reward}, & \text{Ind}(A) \neq \text{Ind}(B) \end{cases} \quad (4)$$

As a starting point, we give a weight of 0.35 to the user's main industry and for each secondary industry a weight of 0.15. The total score is:

$$Total_{ind}(A,B) = 0.35 \cdot \text{main}(A,B) + k \cdot 0{,}15 \cdot \sum_{i}^{k} \text{secondary}_i(A,B) \quad (5)$$

The final score is normalized according to the sum of weights. In the future, the weight values can be re-evaluated, if deemed necessary.

Similarity based on Geographic Location. Two users can be geographically similar when they have a relative distance between them. According to the LinkedIn data available, we have extracted 4 possible distances. These are, from smallest to greatest (and thus denoting higher to lower similarity):

$$\text{Sim}_{geo}(A,B) = \{\text{same city, same country, same continent, no similarity}\} \quad (6)$$

Similarity based on Educational Background. In relation to two users' academic background, we take into account the number and types of degrees that each one has provided. For every type of degree, we have assigned a specific weight, which is a combination of the average years required for it and an extra factor according to their level, as seen in Table 1. The education score is calculated by adding the corresponding values of the user's degrees. The final educational similarity between two users is:

$$\text{Sim}_{edu}(A,B) = \frac{\min(\text{Score}(A), \text{Score}(B))}{\max(\text{Score}(A), \text{Score}(B))} \quad (7)$$

Table 1

Degree weights

Degree	Years	Factor	Final Weight
Associate/Foundation	2	1	2
Bachelor's	4	1	4
Master's	2	1.5	3
Doctorate	4	2	8

General Similarity Formula. The final similarity formula, comparing two users is defined as:

$$\text{Similarity}(A,B) = \sum_i w_i \cdot \text{Sim}_i \tag{8}$$

where Similarity_i is one of the aforementioned similarity measures and w_i is the weight of each measure. In case there are disabled similarity measures, the final value is normalized according to the remaining weights.

Team Similarity and Ranking Algorithm

In order to calculate the similarity among all members of a team, we follow the example of REAGANS et al. (2004). For each team we calculate all possible pairs between its members. Then we calculate each pair's similarity value and then the average of the similarity values of these pairs. So, for all teams T of size n, the ranking value of each team $t_k \in T$, $1 \leq k \leq |T|$, is calculated as:

$$\text{Rank}(t_k) = \frac{\sum_{i=1}^{i=n-1} \sum_{j=i+1}^{j=n} \text{Similarity}(m_i, m_j)}{|\text{combinations}(n,2)|}, \text{ where } m_i, m_j \in t_k \tag{9}$$

Finally, the teams are sorted and presented in a descending order.

Experimentation

In order to assess the correctness and efficiency of PROTEAS, we implemented an online application and asked for the participation of students of two undergraduate university courses in the fall semester of 2013, where they were given assignments to complete in teams of up to 4 people. As not all users have a LinkedIn account, we offered them the option to create an account on our application, where they filled in all the relative information manually. Course A was offered to second-year students and included a theoretical assignment, while Course B was offered to fourth-year students and included a programming one. Students also completed the personality questionnaire. Upon completion of the assignment they filled in another short questionnaire, concerning among other things an estimation of the time they invested in the assignment. In our study 16 teams of Course A participated and 15 teams of Course B (i.e. ~ 60 students in each course). We then manually recreated these teams, calculated each team's similarity measures and checked them against their final assignment grade.

– Team similarity measures and assignment's final grade. As we see in Table 2, although there was no consistent correlation between the general team similarity and the final grade (-0.40 for Course *A*, 0.25 for Course *B*), there was a correlation between skill similarity and the final grade (*A*: 0.22, *B*: 0.48). We observe that Course *B* presents a greater correlation value than Course *A*, a fact not quite unexpected; the assignment for Course *B* was a programming one and thus required the team members' skill set to include many technical skills (such as Java, C++, or HTML). The theoretical assignment of Course *A* didn't have any specific technical prerequisites. No correlation can be calculated for the geographical similarity, as all users in both courses live in the same city, and there is no significant correlation for the language similarity. As undergraduate students took part in our study, it is reasonable that their educational background is similar, as well as the industry they belong to. As a result, there is an almost insignificant correlation for the former, and an inconsistent one for the latter.

Table 2

Correlations between similarity measures and final grade

Similarity Measures	Course *A*	Course *B*
General Similarity	-0.40	0.25
Skill-Grade	0.22	0.48
Language-Grade	-0.19	-0.07
Industry-Grade	-0.28	0.29
Location-Grade	X	X
ducation-Grade	-0.24	-0.25

– Personality traits and final grade. In Table 3 we observe that in Course *A* we have a correlation regarding Conscientiousness, which is in line with observations in Section 3, suggesting that conscientious people have better job

Table 3

Correlations of personality traits with final grade and time

Personality Traits	Final Grade		Weekly Team Hours	
	Course *A*	Course *B*	Course *A*	Course *B*
Openness	0.08	-0.06	0.17	0.24
Conscientiousness	0.33	-0.01	**-0.40**	-0.22
Extraversion	-0.19	-0.01	-0.13	-0.18
Agreeableness	-0.04	**-0.55**	-0.03	**-0.35**
Neuroticism	0.01	0.20	0.42	0.05

performance. Agreeableness is a trait which reflects one's tendency to be acquiescent with other people's ideas. In the case of Course *B*, there is a negative correlation of -0.55 between the Agreeableness trait and the performance in the assignment. This suggests that through initial disagreement, new ideas were put on the table which eventually led to more robust and effective solutions, as we discussed in Section 3. All other traits do not seem to have a significant correlation.

– Personality traits and weekly team work time. It is interesting to note the correlation between personality traits and the average weekly hours a team spent completing the assignment, as seen in Table 3. We observe a negative correlation of -0.35 between Agreeableness and time. We have seen above that less Agreeable teams had better grades, but apparently it was accompanied by a tradeoff. Another interesting finding is the negative correlation between Conscientiousness and time, which is -0.40 for Course *A* and -0.22 for Course *B*. This means that the more conscientious members of a team were more focused on their goal and thus, completed the assignment quicker. Finally, for Course *A* there is a correlation of 0.42 with time, meaning that teams with members having high Neuroticism (e.g. stressful, anxious) needed more time to complete the assignment.

The two assignments were adjusted to the student knowledge level and had different objectives and time constraints. We have nonetheless extracted some interesting findings, as presented above, confirming that alternative criteria can be included in the team building process.

Conclusion

In this paper we have discussed possible ways that the team building process can be improved. Our contribution is PROTEAS, a framework we have developed, which introduces non-traditional variables in team building, such as personality traits of team members. We completed a study with undergraduate students of two courses participating. Although the presented work is at an early stage, we have laid down the foundation stone for further development in the future, and our intention is to extend our framework in many aspects. We are interested in applying PROTEAS in a business setting, where employees have more diverse back-grounds and teams can be created from scratch according to our framework's recommendations. Also, it could be very useful for PROTEAS to be extended with diversity concepts bearing in mind that the key is to find the right balance between similarity and diversity.

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ON EXACTNESS, DEFINABILITY AND VAGUENESS IN PARTIAL APPROXIMATION SPACES

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K e y w o r d s: Partial approximation framework, vagueness, exactness, rough sets, definability.

A b s t r a c t

In this paper, lower/upper, boundary, and negative regions of set approximations, the fundamental concepts of classical rough set theory, have been considered as primitive ones. Assuming that they are independent of each other, a generalized framework for their investigations is outlined. Its main building blocks are base sets and definable sets. Lower/upper approximations, boundaries and negative sets are all considered as definable sets and their mutual interactions are studied. Lastly exact/rough sets are discussed. In generalized framework, four groups of formulae are defined for representing different variants of rough sets. They emphasize distinct features of roughness, and so it may be of highly importance which one is used in practical applications. Some possible choices appeared in authors' publications are mentioned.

Introduction

In Pawlak's rough set theory (PAWLAK 1982, 1991, PAWLAK, SKOWRON 2007a) and its standard generalizations (BANERJEE, CHAKRABORTY 2004, BONIKOWSKI et al. 1998, PAWLAK, SKOWRON 2007b, YAO 2003, YAO, YAO 2012), lower/upper, boundary and negative regions/operators of set approximations are not independent. Usually, two of them are sufficient to define the others.

In this paper, these dependences are relaxed and lower/upper, boundary and negative operators are viewed as *approximation primitives*. As an initial

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step, it is assumed that they are independent of each other, and then their mutual interactions will be investigated.

At first, a general basic framework for our study is outlined (CSAJBÓK 2013, CSAJBÓK, MIHÁLYDEÁK 2012a, 2012b). In the approximation process, the main building blocks are base sets (equivalence classes in the standard case) and definable sets (unions of equivalence classes) obtained by some set operations on base sets. In a general setting, the base sets do not necessarily form a covering. Definable sets constitute all the available knowledge about the objects of interest. Consequently, lower/upper approximations, boundaries and negative sets should all be considered as definable sets.

Vagueness has a central role in the motivation basis of rough set theory. In Pawlak's information-based proposal, it was expressed by the boundary regions of sets represented by the difference of upper and lower approximations. Exactness and roughness of sets are defined via these differences as well. However, in general situations, the above notions and their relations become trickier. For instance, we can definitely say neither that a definable set is exact nor that an exact set is definable. Another important example is that in standard (i.e., equivalence-based) rough set theory boundaries can be defined in three equivalent ways. In generalized theories, however, these definitions lead to different notions of boundaries.

Reformulating of classical rough set theory

Let U be a nonempty finite set of objects.

The well-known Pawlak's rough set theory can be *reformulated* as follows.

- Let ε be an equivalence relation on U. The partition of U generated by ε is called the *base system*, denoted by $\mathfrak{B}$. Its members, the equivalence classes, are called *base sets*.
- Any union of base sets are referred to as *definable* sets. Their collection is denoted by $\mathfrak{D}_{\mathfrak{B}}$. By definition, $\emptyset$ is a definable set.
- Let S be a subset of U ($S \subseteq U$). The *lower approximation* of S, denoted by $\mathsf{l}(S)$, is the union of all base sets that are the subsets of S. The *upper approximation* of S, denoted by $\mathsf{u}(S)$, is the union of all base sets that have nonempty intersection with S. $\langle \mathsf{l}, \mathsf{u} \rangle$ is called the *approximation pair*.
- The *boundary* of S is $\mathsf{bnd}(S) = \mathsf{u}(S) \setminus \mathsf{l}(S)$.
- The *negative region* of S is $\mathsf{n}(S) = (u(S))^c$, where $(\cdot)^c$ denotes the set complementation operator.

According to the above notations, three highly important notions in connection with set approximation can be defined:

- S is *exact* if $\mathsf{l}(S) = \mathsf{u}(S)$;

- S is *rough* if it is not exact;
- S is *definable* if $S \in \mathfrak{D}_{\mathfrak{B}}$.

Relying on the classical Pawlak's set approximation theory, four basic components of an initial set-theoretical general approximation framework can be identified.

1. *Domain*: a set of sets whose members are approximated.
2. *Base system*: a beforehand defined set of some distinguished sets of the domain which serves as the basis of approximations.
3. *Definable sets*: a set of sets whose members are
   - derived from the base system (the base sets are always definable), and
   - designated for possible lower and upper approximations, boundaries and negative regions of the members of the domain.
4. *Approximation pair*: determines lower and upper approximations of the members of the domain by using definable sets.

Generalization of classical rough set theory: the first step

Pawlak's theory is based on a partition of the universe U. By the classical Pawlak's terminology:

- the domain is 2^U (the power set of U);
- the base systems is $U / \varepsilon \subset 2^U$ (the partition of U generated by the equivalence relation ε); its members are the base sets which are called ε-elementary sets;
- $\mathfrak{D}_{\mathfrak{B}}$ is the set of definable sets, where $U / \varepsilon \subseteq \mathfrak{D}_{\mathfrak{B}} (\subseteq 2^U)$, $\emptyset \in \mathfrak{D}_{\mathfrak{B}}$ and any union of ε-elementary sets is also definable.
- $\mathsf{l}(S) = \underline{\varepsilon}(S) = \cup\{B \in \mathfrak{B} \mid B \subseteq S\}$, $\mathsf{u}(S) = \overline{\varepsilon}(S) = \cup\{B \in \mathfrak{B} \mid B \cap S \neq \emptyset\}$.

Accordingly, at the first phase, the notions of base system, definable sets and approximation pair are generalized.

Generalizations of the base system The base system can be generalized by giving up the pairwise disjoint property of U/ε and/or the covering of the universe. Table 1 summarizes the possible opportunities. The most general case gives up the mutually disjoint property *and* the covering of the universe.

Table 1

Relaxing partition

Mutual disjoint property	Covering of the universe	Theory / Framework
✓	✓	Pawlakian rough set theory
∅	✓	Covering-based rough set rheory
✓	∅	One-layered partial approximation framework
∅	∅	**Partial approximation framework**

Formally, the generalized base system $\mathfrak{B} \subseteq 2^U$ is a nonempty family of nonempty subsets of U which does not necessarily cover the universe. The structure which is obtained in such a way is called the *partial approximation framework*.

If $\cup \mathfrak{B} = U$, the base system is called *total*, otherwise *partial*. Nevertheless, the base sets belonging to partial base system may be mutually disjoint. In this case, $\mathfrak{B}$ is called *partial partition* or *one-layered* (CIUCCI et al. 2014a).

Generalization of definable sets Let the set of definable sets $\mathfrak{D}_\mathfrak{B} \subseteq 2^U$ be an extension of $\mathfrak{B}$ in such a way that $\mathfrak{B} \subseteq \mathfrak{D}_\mathfrak{B}$ and $\emptyset \in \mathfrak{D}_\mathfrak{B}$. The members of $\mathfrak{D}_\mathfrak{B}$ are called *definable sets*.

Many types of $\mathfrak{D}_\mathfrak{B}$ can be defined (CSAJBÓK, MIHÁLYDEÁK 2012b). Several examples are the following. $\mathfrak{D}_\mathfrak{B}$ is

- *strictly union type* if $D_1, D_2 \in \mathfrak{D}_\mathfrak{B}$, then $D_1 \cup D_2 \in \mathfrak{D}_\mathfrak{B}$ and $\mathfrak{D}_\mathfrak{B}$ does not contain any other set;
- *intersection type* if D_1, $D_2 \in \mathfrak{D}_\mathfrak{B}$, then $D_1 \cap D_2 \in \mathfrak{D}_\mathfrak{B}$;.
- *Boolean type* if $\mathfrak{D}_\mathfrak{B}$ is a Boole algebra generated by $\mathfrak{B}$.

In a base system $\mathfrak{B}$, our background knowledge about the objects of interest appears. $\mathfrak{D}_\mathfrak{B}$, the set of definable sets, constitutes how the beforehand given background knowledge can be used in an approximation process. From the logical point of view, strictly union type and intersection type of $\mathfrak{D}_\mathfrak{B}$ mean that the disjunction and conjunction of concepts represented by base sets are enabled, respectively. Intersection type works well only together with strictly union type. They together mean that during an approximation process, the conjunction and disjunction of the background properties of the objects of interest are enabled. In the case of Boolean type, partial negation is also enabled beyond the conjunction and disjunction.

Generalization of the approximation pair An approximation pair has to meet the following minimal requirements:

(1) $\mathsf{l}(2^U), \mathsf{u}(2^U) \subseteq \mathfrak{D}_\mathfrak{B}$ – it means that lower/upper approximations must be *definable*;

(2) the functions l and u must be *monotone*, i.e., for all $S_1, S_2 \in 2^U$ if $S_1 \subseteq S_2$, then $\mathsf{l}(S_1) \subseteq \mathsf{l}(S_2)$ and $\mathsf{u}(S_1 \subseteq \mathsf{u}(S_2)$;

(3) $\mathsf{u}(\emptyset) = \emptyset$ (*normality* of u);

(4) if $S \subseteq U$, then $\mathsf{l}(S) \subseteq \mathsf{u}(S)$ – it is called the *weak approximation property*.

Requirements (3) and (4) immediately imply that $\mathsf{l}(\emptyset) = \emptyset$ (*normality* of l).

In general, it is reasonable to assume that the base sets are exactly approximated from lower side. In certain cases, it may also be required of definable sets. Accordingly, a weak approximation pair $\langle \mathsf{l}, \mathsf{u} \rangle$ is

(5) *granular* if $\mathsf{l}(B) = B$ ($B \in \mathfrak{B}$) (granularity of $\mathfrak{B}$, or l is granular);

(6) *standard* if $\mathsf{l}(D) = D$ ($D \in \mathfrak{D}_\mathfrak{B}$) (granularity of $\mathfrak{D}_\mathfrak{B}$, or l is standard).

It is an important question how lower and upper approximations relate to

the approximated set itself. Conditions (1) – (6) may permit that $\mathsf{l}(S) \not\subseteq S$ and/or $S \not\subseteq \mathsf{u}(S)$, or even $\mathsf{l}(S) \cap S = \emptyset$ and/or $S \cap \mathsf{u}(S) = \emptyset$. These observations motivate the following definitions.

Let $S \subseteq U$. A weak approximation pair $\langle \mathsf{l}, \mathsf{u} \rangle$ is

(7) *lower semi-strong* if $\mathsf{l}(S) \subseteq S$, i.e., l is contractive;

(8) *upper semi-strong* if $S \subseteq \mathsf{u}(S)$, i.e., is extensive;

(9) *strong* if it is lower semi-strong and upper semi-strong at the same time, i.e., each subset $S \subseteq U$ is bounded by $\mathsf{l}(S)$ and $\mathsf{u}(S)$: $\mathsf{l}(S) \subseteq S \subseteq \mathsf{u}(S)$;

(10) Pawlakian if

- $\mathsf{l}(S) = \cup\{B \mid B \in \mathfrak{B}, B \subseteq S\}$,
- $\mathsf{u}(S) = \cup\{B \mid B \in \mathfrak{B}, B \cap S \neq \emptyset\}$,

provided that $\mathfrak{D}_{\mathfrak{B}}$ is strictly union type.

The Pawlakian approximation pair $\langle \mathsf{l}, \mathsf{u} \rangle$ is a direct generalization of the pair $\langle \underline{\varepsilon}, \overline{\varepsilon} \rangle$. Clearly, it is a strong one.

Further generalization: boundaries

Definable sets constitute all the available primary and derived knowledge about the objects of interest. Consequently, like as lower and upper approximations are definable sets, boundaries must be definable as well.

Let $S \subseteq U$. In classical rough set theory, the following definitions of boundaries are equivalent, but they lead to different notions of boundaries in the general case.

(1) $\mathsf{b}_1(S) = \mathsf{u}(S) \setminus \mathsf{l}(S)$

(2) $\mathsf{b}_2(S) = \cup(C^{\mathsf{u}}(S) \setminus C^{\mathsf{l}}(S))$, where

- $C^{\mathsf{l}}(S) = \{B \mid B \in \mathfrak{B}, B \subseteq \mathsf{l}(S)\}$
- $C^{\mathsf{u}}(S) = \{B \mid B \in \mathfrak{B}, B \subseteq \mathsf{u}(S)\}$

(3) $\mathsf{b}_3(S) = \cup\{B \mid B \in \mathfrak{B}, B \cap S \neq \emptyset, B \not\subseteq S\}$

At first, it should be noted that none of $\mathsf{b}_1(S)$, $\mathsf{b}_2(S)$ and $\mathsf{b}_3(S)$ will be definable necessarily, hence these formulae cannot be generalized directly. Nevertheless, under different conditions one or more of them become definable.

- If the approximation pair $\langle \mathsf{l}, \mathsf{u} \rangle$ is Pawlakian and $\mathfrak{B}$ is one-layered, b_1 is definable.
- If $\mathfrak{D}_{\mathfrak{B}}$ is strictly union type, b_2 and b_3 are also definable. In addition, if $\langle \mathsf{l}, \mathsf{u} \rangle$ is Pawlakian, then $\mathsf{b}_1(S) \subseteq \mathsf{b}_2(S)$, where $\mathsf{b}_1(S) = \mathsf{b}_2(S) \Leftrightarrow \mathsf{b}_2(S) \cap \mathsf{l}(S) = \emptyset$ $(S \subseteq U)$ also holds (CSAJBÓK, MIHÁLYDEÁK 2013).

Another observation that both b_1 and b_2 are „independent" of the set S itself, they solely depend on the lower and upper approximations of S. It may happen that $S \cap \mathsf{b}_1(S) = \emptyset$ or $S \cap \mathsf{b}_2(S) = \emptyset$ even if $\mathsf{b}_1(S), \mathsf{b}_2(S) \neq \emptyset$.

On the contrary, b_3 only depends on the set S (of course, with respect to the given base system), it is independent of the lower and upper approximations of S. Furthermore, if $\mathsf{b}_3(S) \neq \emptyset$, $S \cap \mathsf{b}_3(S) \neq \emptyset$. This type of boundary can be viewed as a real representation of the informal notion of boundaries.

Further generalization: negative regions

In classical rough set theory, the negative region is $\mathsf{n}(S) = (u(S))^c$ ($S \subseteq U$). Of course, it must be definable as well. However, even in covering-based rough set theory, $(u(S))^c$ is not definable necessarily. A possible solution may be that the lower approximation of $(u(S))^c$ is taken, i.e., $\mathsf{n}(S) = \mathsf{l}((u(S))^c)$. In this way, definable negative regions are obtained.

In Pawlak's rough set theory, the lower approximation $\mathsf{l}(S)$ of S is also called the *positive region*, and $\mathsf{l}(S) \cap \mathsf{n}(S) = \emptyset$ trivially holds owing to their constructions. In the general case, however, the weak approximation property $\mathsf{l}(S) \subseteq \mathsf{u}(S)$ immediately implies that $\mathsf{l}(S) \cap \mathsf{l}((u(S))^c) = \mathsf{l}(S) \cap \mathsf{n}(S) = \emptyset$ also holds. It is in accordance with the informal meaning of positive and negative properties.

It is a question to be investigated whether negative regions of sets can be treated as an approximation primitive, i.e., independently of lower/upper approximations and boundaries. If the answer is yes, the next question is that the relation $\mathsf{l}(S) \cap \mathsf{n}(S) = \emptyset$ as a minimum requirement for positive and negative regions is required or not.

Exact sets

As before, at first, the case of classical rough set theory is investigated. Accordingly, $S \subseteq U$ is *exact* if $\mathsf{l}(S) = \mathsf{u}(S)$, and so $\mathsf{l}(S) = S = \mathsf{u}(S)$ by the construction of l and u in classical rough set theory. This definition only works well when the approximation pair is strong, i.e., $\mathsf{l}(S) \subseteq S \subseteq \mathsf{u}(S)$. For instance, if the base system is total and the approximation pair $\langle \mathsf{l}, \mathsf{u} \rangle$ is Pawlakian, $\langle \mathsf{l}, \mathsf{u} \rangle$ is strong. However, when the base system is partial, the approximation pair generally is not strong even if it is a Pawlakian one. Indeed, if $\langle \mathsf{l}, \mathsf{u} \rangle$ is Pawlakian, it is surely lower semi-strong, i.e., $\mathsf{l}(S) \subseteq S$ ($S \subseteq U$), but $S \subseteq \mathsf{u}(S)$ does not hold for all $S \subseteq U$.

Moving on, let $\mathfrak{B}$ be partial and $\langle \mathsf{l}, \mathsf{u} \rangle$ be Pawlakian. It may happen that $\mathsf{l}(S) = \mathsf{u}(S) \subsetneq S$ for a set $S \subseteq U$. On the contrary, it may occur for a definable set S that $\mathsf{l}(S) \subsetneq \mathsf{u}(S)$ holds. These observations mean that neither „an exact set is definable" nor „a definable set is exact" holds necessarily according to the classical definition of exactness.

In general case, exact sets can be defined, e.g., by lower and upper approximations as follows: $S = \mathsf{l}(S)$ or $S = \mathsf{u}(S)$. If both $S = \mathsf{l}(S)$ and $S = \mathsf{u}(S)$ hold, S can be viewed as absolutely exact set (CIUCCI et al. 2014b).

It is also a question to be investigated whether the notion of exact set could be an approximation primitive.

Rough sets

In rough set theory, a set $S \subseteq U$ is *rough* if it is not exact, i.e., $\mathsf{l}(S) \neq \mathsf{u}(S)$ according to the classical Pawlakian definition. However, there may be a number of sets with the same lower and upper approximations. Therefore, the pair $\langle \mathsf{l}(S)\ \mathsf{u}(S) \rangle$ represents a class of sets which is called the *rough set*. Its further definitions and detailed investigations can be found, e.g., in BANERJEE, CHAKRABORTY (2004) and the references therein.

In generalized framework, the following definitions of rough sets may arise:

1. $\langle \mathsf{l}(S), \mathsf{u}(S) \rangle$ (it is the classical Pawlakian approach);
2. $\langle \mathsf{l}(S), \mathsf{n}(S) \rangle$;
3. $\langle \mathsf{l}(S), \mathsf{b}_i(S) \rangle$ ($i = 1,2,3$);
4. $\langle \mathsf{u}(S), \mathsf{b}_i(S) \rangle$ ($i = 1,2,3$).

These formulae generate the same partition of the power set of U in classical rough set theory. This is because the operators n, b_i ($i = 1,2$) can be derived from from the operators l and u. The operator b_3 is independent of l and u, but the boundaries b_1, b_2, b_3, are equivalent in classical rough set theory. Therefore, in this case, any one of the previous formulae can represent rough sets. It should be noted that in these representations, exact sets appear as special rough sets.

However, these formulae may lead to different partitions of the power set of U in generalized framework. Therefore, formulae 1–4 may represent distinct variants of rough sets emphasizing their different possible features. Consequently, it may be of highly importance in practical applications of generalized set approximation which formula represents rough sets.

If it is laid emphasis on the positive/negative features of concepts, the second formula must be applied. The situation in which the relation $\mathsf{l}(S) \cap \mathsf{n}(S) = \emptyset$ holds is well known and studied in detail as orthopair (CIUCCI 2011, CIUCCI 2014). A possible application was discussed in (CSAJBÓK, MIHÁLYDEÁK 2011). However, in case of conflicting information, there may be something both positive and negative which situation has to be handled in some way as well. This is which happens, for instance, in paraconsistent logics (PRIEST et al. 1989, 2013, PRIEST 2002), Atanassov's IFS (ATANASSOV 1986, 1999, 2012, CATTANEO, CIUCCI 2006), generalized orthopairs (CIUCCI et al. 2014a) and relative sets (MOUSAVI, JABEDAR-MARALANI 2001, 2002).

A number of studies deal with the relationship between rough set theory and fuzzy set theory. There are many opportunities to establish relations between them (DUBOIS, PRADE 1987, DUBOIS, PRADE 1990, DUBOIS, PRADE 1992, CHAKRABORTY 2011, YAO, ZHANG 2000). In this case the third version of the definition of rough sets is the relevant one.

Fuzziness in partial approximation framework was investigated in (CSAJBÓK, MIHÁLYDEÁK 2013). The investigation was started from Pawlakian approximation pair, and created three partial membership functions: optimistic, average, and pessimistic ones. These fuzzy functions provide *special type of fuzziness* on the universe: all of them are *partial functions* and derived from the observed data relatively to available knowledge about the objects of the universe. In (MIHÁLYDEÁK 2013), relying on the above partial fuzzy functions, three different semantic notions of logical consequence relations were introduced in partial first-order logic.

Lastly, it should be noted that if the notion of exact sets is viewed as an approximation primitive, the representation of rough sets cannot be defined independently from exact sets.

Conclusions and future work

In this paper, starting from the classical Pawlakian rough set theory, general formulations of approximation spaces have been outlined. Three underlying approximation components (domain, base systems, and definable sets) and five approximation primitives (lower/upper, boundary and negative operators) have been identified. Possible basic structures of these components and mutual interactions of approximation primitives have been investigated. Some questions to be answered concerning approximation primitives have been posed.

Further investigations of algebraic structures of underlying approximation components are required. Next, it should be important to take a survey of algebraic structures of rough sets in different approximation spaces.

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THE USAGE OF IT PROJECTS EVALUATION METHODS COVERING THE SPECIFICATION OF SOFTWARE PRODUCER' ACTIVITIES, A CASE STUDY

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K e y w o r d s: projects evaluation methods, Delphi method, UCP method, estimate factors, environmental complexity factors, technical complexity factors, evaluation criteria.

A b s t r a c t

The usage of the evaluation concerning IT projects by software producers constitutes a crucial element of their preparation and realization. From many generally accessible methodologies the authors chose two methods (Delphi and UCP[1]) as well as undertook an attempt of analyzing obtained results. Conducted results will support the evaluation of newly realized projects.

The objective is an attempt of comparing the efficiency of selected methods of pricing the software with indicating the areas of their usage as well as factors which influence the realization of those projects.

Introduction

The issue of estimating constitutes a crucial and very arduous stage in the software production cycle. One has to agree with the words of Fred Brooks „In a given post it is very difficult to conduct a definite, convincing and risky defense of estimating which was created as a result of some quantitative analysis, is supported by small amount of data and faces disapproval mainly because of the managers' intuition". According to the definition word „to estimate" means „offer something approximately", „to evaluate". In IT sector one expects providing exact costs connected with the realization of a particular

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[1] Use Case Points (UPC) is a current technique for measuring functionality of a software system.

undertaking. The scope of costs is determined by regular factors such as: particular terms, goals or business obligations. During the years where IT sector was developing many methods of estimating appeared, they are more or less efficient depending on the conditions and resources, experience, specificity of the project have major significance as far as these conditions are concerned. The article is an attempt of comparing the efficiency of selected methods of pricing the software with indicating the areas of their usage as well as factors which influence the realization of those projects. To minimize the risk connected with failure of the project realization the authors suggest using different methods of estimating. For long-term projects they recommend to gather obtained results (results of estimation) each time. It will enable the verification of planned figures with the actual realization as well as conduct analysis to introduce repair actions. The usage of the measure of estimating efficiency (MES), which is to be described below, allows the manager of the project and managers to limit underestimating or overestimating the project.

For many years the authors have been dealing with both theoretical and practical aspects of IT projects. They actively participate in IT undertakings realized for the sake of different economic entities, with special focus on their economic efficiency.

Selected methods of estimating software

According to the data published annually in CHAOS Chronicles by the organization The Standish Group International, about 66% of projects from the IT sector realized within the borders of USA ends up with a failure (WINIARSKI 2011). In Poland there is no systematic research in this area due to high costs.

For many years the consequences of accurate and/or faulty decisions have been visible in the economy and described in professional literature. One of the most basic issues in planning IT undertakings is precise determination of their efficiency. On one hand, it is connected with rationalizing the expenses, on the other – with achieving, in proper conditions, optimal appropriable and economic effects (BOEHM 1981, DUDYCZ, DYCZKOWSKA 2006, CEGIEŁKA, ZALEWSKI 2000). It is worth using the measure of estimating efficiency (MES) for this purpose which is calculated according to the formula:

$$MES = (CR/CZ) \cdot 100\%,$$

where:
CR – number of hours planned for realization in particular period,
CZ – number of hours realized in particular period.

All repair and correction activities connected with selected method and the change of structure (organization) of the company should provide the optimal value of the measure. According to the practice the typical division for the measure MES is: <80%; 120%>. Preventing both underestimating and overestimating enables meeting the project requirements.

The most popular methods of estimating are informal techniques and techniques transferred from classic economy (GÓRSKI 2000). They are, among other things, expert's opinion, estimating by analogy and estimate models. Each method can be used according to two main rules of estimating bottom-up or top-down. Estimating with bottom-up method starts with the analysis of particular components. They are added up and necessary operations on the sets are done obtaining the total picture of the project. Top-down estimating is a reversed process – it begins with looking at the project in a „bird's eye" way and particular elements are treated as its components.

The expert's opinion has been popular for many years as a method of predicting the scope and costs, based on the estimates of individuals who have participated in projects similar to the one they have to analyze (MCCONNELL 2006, KACZOROWSKI 2010). However, it is a totally subjective method and not described by any strict algorithm. Nevertheless it provides surprisingly good results (LIPSKA, TAŃSKA 2002, WINIARSKI 2011). It is especially used in case of innovative projects (DĄBROWSKI, SUBIETA 2005) because it does not require (in necessary manner) any quantitative data.

Methods of estimating projects recommended by the authors in regards to projects realized as a part of sustaining the sector system to serve local government units are Usage Case Points Method and Delphi Method.

The first one is UCP method which is a derivative of another known method used for estimating the scope of software, the method of functionality points which is based on screen projects and the architecture of the system. The creator of this method is Gustav Karner (KARNER 1993). He introduced the methodology and defined the importance of environmental factors that specify the complexity of the organization, the technical complexity of factors that specify the technical properties of the product and the actors of the system.

In case of UCP method the architecture and screens were substituted with specificity of requirements in a form of cases of usage. Moreover, there are four categories of parameters taken into consideration (ALBRECHT 1979):

– the factor of environmental complexity which reliable establishment enables the level of organization realizing the project; the more importance the factor has, the more it influences the decrease of work consumption of the undertaking;

– the factor of technical complexity which identification enables establishing the level and difficulty as a part of particular technology; the increase of that factor influences the final increase of work consumption estimation;

– actors, the number of external beings (identifying closer and further surroundings);

– cases of usage (number of functions crucial from the perspective of actors).

In a company dealing with the production of software the following procedure of behavior was worked out.

All 13 factors of technical complexity are assigned to proper numerical value which enables the estimation of technical aspects of the product (Tab. 1).

Table 1

Technical factors with numerical value

Technical factor	Value
Dispersed system	2.0
Efficiency	1.0
Efficiency for the final user	1.0
Complex inner processing	1.0
RE-usage	1.0
Ease of installation	0.5
Ease of usage	0.5
Mobility	2.0
Ease of introducing changes	1.0
Compatibility	1.0
Special protection	1.0
Dependency on external libraries	1.0
Additional training for users	1.0

Source: KARNER (1993).

Moreover, 8 factors of environmental complexity were indicated. All of them were assigned to the value determining their final estimation (Tab. 2).

Table 2

Environmental factors with numerical value

Environmental factors	Value
Knowledge of the project	1.5
Experience in creating application	0.5
Experience in creating application oriented for the object	1.0
Skills of main analist	0.5
Motivation	1.0
Stability of requirements	2.0
Part-time workers	-1.0
Software language difficulty	-2.0

Source: KARNER (1993).

After determining the environmental and technical factors, one has to evaluate the cases of system usage. The first step involves evaluating the complexity of actors (Simple, Average Complexity, Complex); on its basis one establishes the modulus Unadjusted Use Cases Weight (UUCW). Then the value of actors is established (1, 2, 3), on its basis one creates the value of modulus Unadjusted Actors Weight (UAW). Summing two modulus: UUCW and UAW enables the calculation of Unadjusted Use Case Point (UUCP). The following step of the procedure is multiplying the value of UUCP, by technical (TCF[2]) and environmental (ECF[3]) factors, which enables us calculating points of case usage UCP.

$$UCP = UUCP \cdot TCF \cdot ECF$$

The last stage is changing the points of cases of usage to work consumption expressed in hours per person. To do that UCP is multiplied by the Productivity Factor PF, which value expresses the number of hours per person for one point of the case of usage[4]. In calculations the authors decided that the value of 20 working hours is 1 PF.

The second aforementioned method – Delphi Method is based on independent estimating conducted by few experts. However, it requires having qualified specialists in particular field (and access to them) in one's personnel resources.

Algorithm of Delphi method includes the following steps:

– providing experts with proper materials, documentation and time necessary for becoming familiar with them;

– exchange of opinions on the project, analysis of remarks and comments;

– anonymous estimation of work consumption by each expert;

– working out the results of voting, transferring them to estimate form and preparation of estimate report;

– presenting the evaluation of other experts and average estimation, discussion and renewed analysis of factors influencing the work consumption;

– repetition of all action until obtaining approximate estimates of work consumption by the experts or calculation of average of obtained results. This average should take into consideration the pessimistic evaluation (P) and the optimistic one (O) with the value of 1 as well as average value (A) of 4;

[2] Technical Complexity Factor.

[3] Environmental Complexity Factor.

[4] According to definition the value of 20 working hours is recognized as 1 PF (different sources). The author of the method – Gustaw Karner suggested a predictor PF equal to 20 working hours per one UCP, but it can belong to an interval of 15-38 working hours (Karner 1993).

– final estimating of work consumption (OKP) according to the formula: (P + 4A + O)/6.

UCP Method as well as Delphi Method can be used by the managers of short-term and long-term T projects with different scope of influence.

Criteria of evaluation and results of research

The authors chose projects to constitute empirical material to verify the reliability of offered methods. For the purpose of analysis they chose projects (Tab. 3) realized as a part of a system to serve local government units PUMA (Start-up Platform for Application Modules). These projects (six projects) were realized in similar time intervals. To estimate six project the same environmental and technical factors were used (UCP Method) as well as the experts with comparable knowledge and experience (Delphi Method). The budget of these project did not exceed 2500 hours. The projects cover different elements of functionality of integrated IT system PUMA, such as new module, functionality or integration with external systems. Table 3 presents eight projects (code and name of the project) which were analyzed.

Table 3

Selected projects enabling estimating

Code of the project	Name of the project
51	Integration with external documentation circulation
58	Module GODP
61	Functionality to making functionality available
63	Reporting for GODP
64	Adjusting GODP for the Association of Communes
65	Integration with SIDAS system

Source: authors' own work.

Table 4

The results obtained by researching selected projects

Code of the project	Delphi method	UCP method	Averaged method	Realized budget
51	141	261	201	120
58	2,122	2,103	2,112	2,521
61	123	164	144	122
63	1,012	780	896	1,308
64	616	423	520	584
65	154	209	181	148

Source: authors' own work.

Each module was independently estimated using methods: Delphi and UCP (Tab. 4). The estimated budget was presented in operating hours (h). Moreover, the analysis was widened by averaged estimate for the methods above calculated using a Simple method of arithmetic average.

Discussing the results

Figures (1–5) present the values of planned and realized estimates for particular projects:

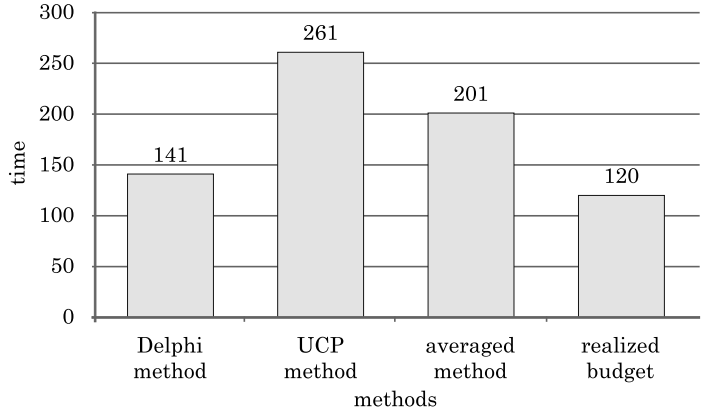

Fig. 1. Integration with external system of document circulation according to Delphi, UPC methods

Estimates conducted using UCP method are almost two times higher in comparison to Delphi method (Fig. 1). What is important, realized budget is 20 working hours lower that estimates done using Delphi method.

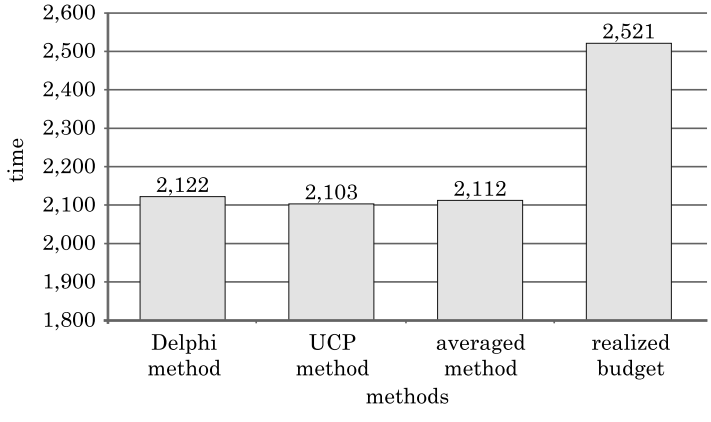

Fig. 2. Module GODP according to Delphi and UCP methods

In case of module 58 estimate done by using analyzed methods provided approximate results: 2,122 (Delphi method) and 2,103 (UCP method) whereas the realized budget was lower in 400 working hours (Fig. 2). Specific situation was caused by the change of legal regulations.

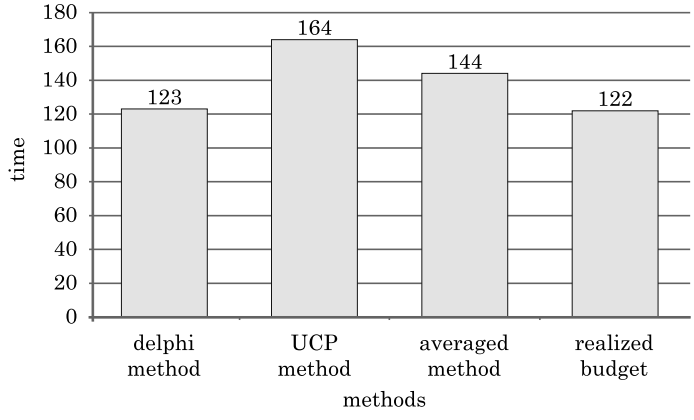

Fig. 3. Functionality to making functionality available according to Delphi and UCP methods

Figure 3 illustrates the difference (40 working hours) in estimates done using Delphi method (123) and UPC method (164). At the same time it is worth noticing the lack of difference between Delphi method and realized budget (convergence of results for module 61).

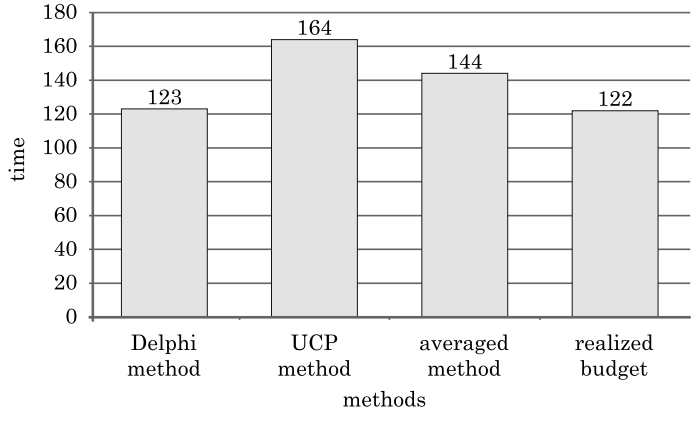

Fig. 4. Reporting for GODP according to Delphi and UCP methods

The collation of selected methods characteristic for module 63 (Fig. 4) illustrates the fact of underestimation of labor consumption both using Delphi method and UCP method. It is 300 working hours.

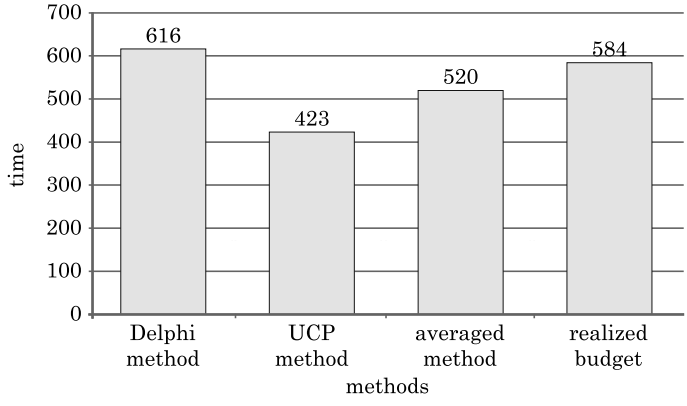

Fig. 5. Adjustment of GODP for the Association of Communes according to Delphi and UCP methods

According to Figure 5 the significant differences in estimates obtained using each method are visible. The calculations done using Delphi method are more approximate to realized budget.

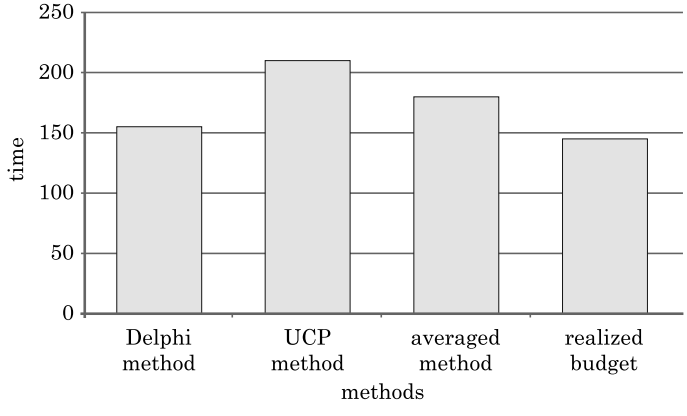

Fig. 6. Integration with SIDAS system according to Delphi and UCP methods

Interesting results were obtained for module 65, especially as in this case the realized budget (148) is lower than the one calculated using Delphi method (154) and UCP method (209). The difference is not significant and in case of the first method it is (6 working hours) and in case of the second one it is (61 working hours).

On the basis of aforementioned data one can ascertain that in case of realization concerning minor projects (budget up to 2,500) the most approximate estimates of projects in relation to their later realization derive from

Delphi method. For all of six projects realized using this method the budgets were approximate to actually realized works.

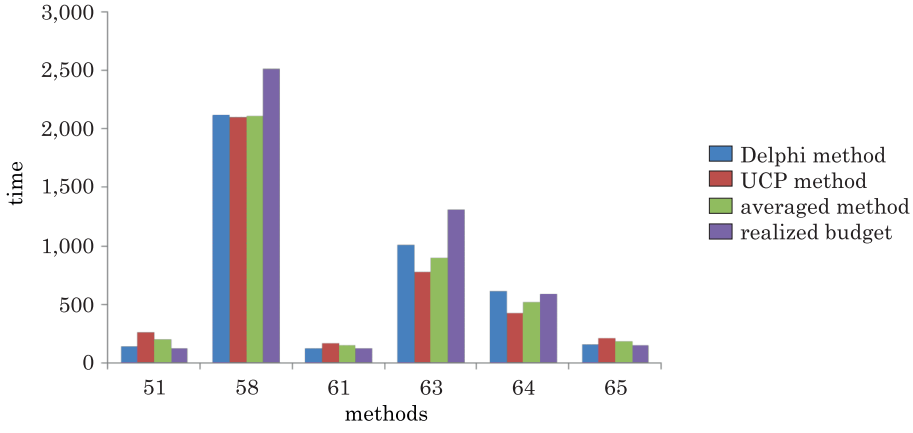

Fig. 7. Collation of research results according the Delphi method, the UCP method, the Averaged result, the Realized budget

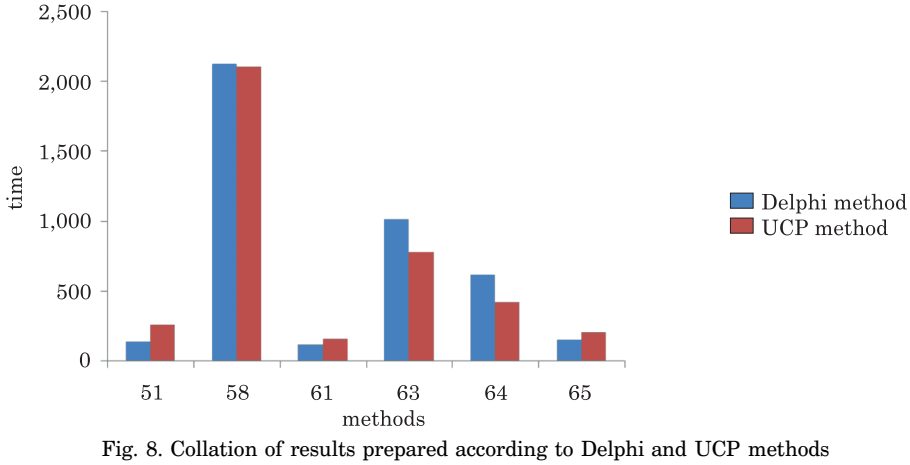

Fig. 8. Collation of results prepared according to Delphi and UCP methods

Analyzing the results obtained using: Delphi and UCP methods one can ascertain for six researched modules:

– Modules 51, 61, 65 present a lower value for Delphi method;

– Module 58 presents results approximate two both methods;

– Modules 63 and 64 are characterized by lower estimate when UPC method is used and higher when Delphi method is used.

Depending on the type and specificity of realized project one can notice that in the case of a project covering the addition in a form of a new module to

PUMA system the estimation prepared by using the method UCP is clearly underrepresented whereas in the case of estimating projects including the integration on system PUMA with external systems of other producers the estimate prepared by using UCP method is clearly inflated.

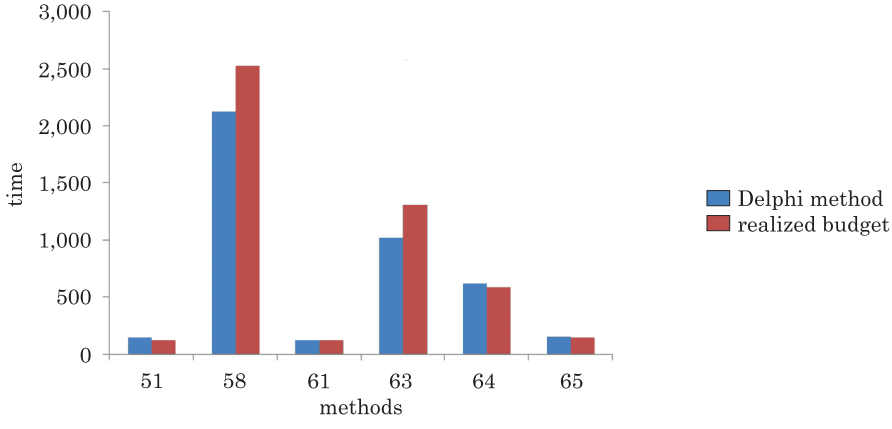

Fig. 9. Collation of results obtained using Delphi method and realized budget

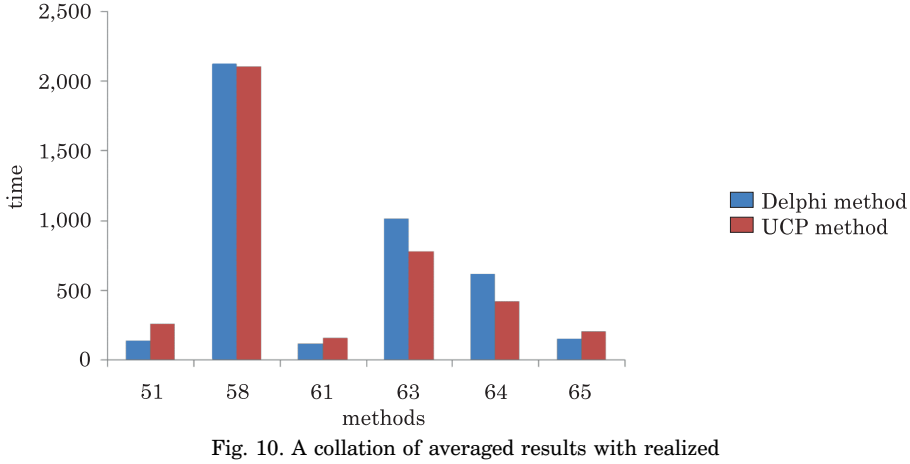

Fig. 10. A collation of averaged results with realized

Summing up aforementioned considerations (Fig. 1–6) one can notice that Delphi method offers better estimates of the projects which are taken into consideration.

Conclusion

Many factors (technical and environmental) influence the change of realization concerning IT projects. The authors undertook an attempt of indicating the most crucial reasons for deviation from assumed estimates during the realization of the analyzed projects mentioned above (Integration with external system of document circulation, GODP Module, Functionality to make functionality available, Reporting for GODP, Adjusting GODP to Association of Communes, Integration with SIDAS system). The basic ones include:

– The changes of legal regulations influencing the scope of project realization;

– Changes of resources realizing particular projects (rotation of employees);

– Lesser knowledge on basis of content and experience in the case of realization of new functionalities different from those used while developing the existing ones;

– Organizational changes (especially changes in management);

– Wide spectrum on basis of content concerning realized projects.

While planning and then realizing IT projects one has to establish the budget. In such a way one estimates both the conditions in which they are to be realized as well as conditions in which the effects of undertaken actions will be possible to observe. The final and detailed evaluation of results will be conducted after the project is finished. In such a way the base which constitutes a compendium of knowledge is created and modified. Future managers may use it while planning new projects.

The authors recommend Delphi method as up till now the knowledge and experience of experts offer the most reliable results. They will continue the research in the area of other aspects of the process of producing software trying to bring together academic knowledge and practical knowledge.

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Guide for Autors

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