Flexible construction process management using robust strategy

A. Karlowski[a] and J. O. Paslawski[a]
[a]Institute of Structural Engineering, Poznan University of Technology, Poland
E-mail: ark_kom@wp.pl, jerzy.paslawski@put.poznan.pl

ABSTRACT

Management of construction processes is extremely difficult due to the nature of the construction industry. The ability to make the right decisions during the construction process ensures online monitoring of process in progress and the environment. Flexibility seems to be an advantage for solve mentioned problems in the case of uncertainty. The presented example shows the possibility of flexible management of construction processes using new technology based on robustness build on the system. Internal curing technology using Phase Change Material additive that protect the top layer of concrete from freezing due to the greater thermal inertia is a strategy of flexibility based on robustness. The second (complementary) strategy is adaptability that provides the ability to heat the concrete in freezing emergency. With the described actions one can mitigate risk grace to achieving the required concrete frost resistance in a relatively short period of time (night temperature drop in the fall/winter period).

Keywords -
Flexibility, risk management, construction process, low temperature, concrete, change phase material

1 Introduction

Construction process management is not an easy task due to the nature of the construction industry. It stems from the nature of construction, which manifests itself among others: 1. Long-chain quality (complex construction processes) 2. The commitment of the human factor (still largely artisanal nature of many processes - a small part of automation and robotics) 3. Dependence on the surrounding environment (e.g. weather conditions).

According to the classification of the common problems in the construction made by Pachon and Jacob [1], four following can be regarded as a key:

- inaccurate planning
- changing requirements
- miscommunication
- imprecise execution.

Of course there are many other causes of problems in the management of construction processes that are classified in other categories, e.g.: aversion to implement new technology, extending the construction period, adverse financial conditions, low productivity. The problems mentioned above are largely due to the distortion of construction processes, which result from the typical causes of five sources:

1. investor (e.g. change of requirements in progress)
2. designer (e.g. the errors / omissions in the project documentation)
3. contractor (e.g. the lack of adequate capacity in the circumstances to suspend works)
4. supplier (e.g. delayed / incorrect delivery)
5. environment (e.g. weather conditions).

The negative impact of the environment will not only exceed the budget or not meeting the deadline of project, but also generates a risk of non-quality. This means not only a loss to the contractor, but also social problems (ie. limiting the operation of the airport, a bridge or highway). Numerous spectacular examples (airport in Berlin [2], the Central Artery/Tunnel Project (CA/T) in Boston [3], the airport in Modlin [4]) justify seeking a systemic solution. The use of a flexible approach seems to be an attractive proposition due to the success of this type of solution in flexible manufacturing systems used successfully in other areas of the classical production (flexible manufacturing systems). Naturally, one should be aware of the difference resulting from the adjustment to even the changing needs of the market, while in the case of the construction industry in terms of changing conditions of environment. In this perspective, flexibility is defined as the possibility (but not - the obligation) to adapt actual technological options to the identified (or expected) environmental conditions. Of course, different definitions of flexibility could be expected regarding to the different phases of the life cycle of a building, but the fact that it is important to track a changing environment and processes in progress and current adaptation to change.

The aim of the article is to show the applicability of flexibility in managing construction processes in a changing environment as a remedy for common problems concerning exceeding budget, deadline of the project date and the risk of not meeting the quality requirements.

The theoretical part of the article presents a review of literature and basic assumptions of flexibility in the management of the construction industry. The applicability of flexibility is illustrated on concrete case study in low temperature conditions. Applied technological flexibility consisting in the addition of PCM, which enables the proper maturation of concrete, despite short-term reduction in temperature below 0 ° C in the initial stage of maturation in the absence of a special protection. The beneficial effects of robustness as the flexibility built into the construction process by modifying the material were indicated

2 Flexibility in construction industry

Analyzing the typical recommendations for the implementation of construction processes under varying environmental conditions should be taken into account firstly the desire to minimize the likelihood and impact of negative events and to maximize the probability and the use of the emerging opportunities. With the anticipation of margin of maneuver can be implemented not only in accordance with the most favorable scenario, but also in the case of a negative scenario. It must therefore have a range of options to customize the realization methods to the situation. The second condition for success is to monitor the situation. This makes it easier to adapt to changes on an ongoing basis and continue construction processes, despite the disruption and to limit their impact on the results. The third element is the use of a situational approach - level of flexibility to adapt to the current conditions. Too little will not allow the flexibility to adapt and too much flexibility may result in chaos.

2.1 Literature review

When analyzing the literature related to the flexibility in the construction management works of Kaplinski should be noted: concerning management of cyclical construction processes [5] and the superposition of them [6]. Attempts to apply the flexible production systems in the construction industry were described by Reichelt [7] and Halpin [8]. However, it was aimed to implement of flexible systems in typical mode in the treatment of stone materials. De Neufville was pointed the role of flexibility in engineering design as opposed to the search for one best solution, while the operating conditions change, which makes it more efficient to prepare for the changes [9, 10]. Walker with the team [11, 12] introduced the concept of flexible management of construction processes using non-technical management elements (commitment, teamwork). Thomas with team pointed sense of the use of flexibility in case of changing environmental conditions [13, 14, 15, 16, 17]. An important step in implementing a flexible approach is Olsson's work [18], which emphasizes the development of flexible construction project management tactics. The use of flexible management in the mining industry was described by Kazakidis and Mayer [19]. Saari *at al.* [20] developed a system procedure of flexibility in the management of construction facility in the operation stage. An important step in the implementation of a flexible approach was the concept of risk and uncertainty in the implementation of construction projects based on three elements (Permirova *et al.* [20]): learning from examples, application of flexibility and quick decisions in response to changing situation. Paslawski proposed flexible approach to managing the construction process at the 25th Conference ISARC [22]. At the same time Karlowski described the implementation of a flexible approach in the concrete work [23]. Subsequent work by the authors of the article was to implement a flexible approach to noise management [24], airport construction, concreting monolithic objects, and repair of bridge and manufacturing of modifiers for cement concrete [25]. Shahu *et al.* [26] point out the different criteria for evaluating the success of the project using a flexible approach. The typical approach is based on the performance (efficiency) associated with meeting the budget and deadline for completion by the requirements of quality specifications. However, the wider look at the effects of application flexibility allows the assessment of effectiveness and added value - suitability for the customer / user. An important step in the implementation of flexibility in the construction industry, taking into account the multi-stage investment process is the project Cileccta whose authors (Falwett *et al.* [27] take into account not only the analysis of life cycle costs (LCC), but also its impact on the environment (e.g. CO_2). In 2014 Hajdasz attempted to use the flexibility in the management of cyclical processes on the example of monolithic structure using sliding formwork [28]. As is clear from the literature review a flexible approach is used in the construction management for almost 30 years, but it should be emphasized differences of approach for levels of management and life-cycle phases of a building object.

2.2 Theoretical basis of flexible approach

Theoretical basis of application flexibility based on four elements:

1) contingency theory
2) organizational equilibrium theory
3) law of requisite variety

4) foundations of systems theory

Contingency theory assumes that there is no single best method of action, but it depends on the external and internal conditions. The main idea is based on the contingency that the organization should have the ability to choose the appropriate course of action depending on the specific situation. Contingency theory is the opposite to often encountered practice to striving for universal methods of action applicable in any situation. It should be emphasized contingency evolution from the original concept developed by Lawrence and Lorsch [28] to dynamic contingency assuming proactive approach [30]. From the point of view of the proposed approach contingency has a fundamental importance because of adaptation of the execution options to the specific operating conditions.

Organizational equilibrium theory shows the benefits of operation continuity under equilibrium conditions also in case of the involvement of additional resources for this purpose. This is justified by higher operating costs (or lack of it) beyond the state of equilibrium and the costs of restoring equilibrium compared to the cost of maintaining the continuity of balance. Organizational equilibrium theory is a fixed configuration by Mintzberg, while according to Volberda [30] is the ability to adjust to changes due to the flexibility in the organization. Presented flexible approach based on the idea of the benefits of the flexibility in the system, even if it means the need of incurring additional costs.

The law of requisite variety also called Ashby's law is closely related to the theory of organizational equilibrium described above [31]. The basis of maintain the balance at a given stage are: 1) finding the system in equilibrium in the previous step, and 2) the availability of the necessary variety of measures of control (greater than or equal environment characterized by variability) at the current stage. From the viewpoint of flexibility of this approach, it is important to point out certain boundaries of flexibility above which it will not be used.

Theoretical basis resulting from the systems theory include two assumptions [32]: 1) decentralization and 2) focus on key factors. Maintaining balance and adapt to change is the most efficient and effective when it is focused on the action at their source or near these areas. In the case of the construction process our attention should be focused on the operational level. In the proposed approach, flexible management is focused on the key risk factors and uncertainties.

The analysis of the applicability of flexibility may affect different phases of the life cycle and the different levels of management. Admittedly it seems very effective use of flexibility in the design phase (when the level of uncertainty is extremely high). However, at the stage of construction the lack of flexibility can mean not only the loss arising from the cost of rework (repair), but also because low quality can generate increased costs in the operation phase (which can be illustrated with repeated repair sections of roads / streets). In the operation phase should be aware of the need to adapt to changing user requirements. Must account of the possibility of generating problems in the operation phase resulting from errors in the phase of design or construction This justifies a comprehensive look of flexibility at the life cycle of building, as illustrated in Fig. 1.

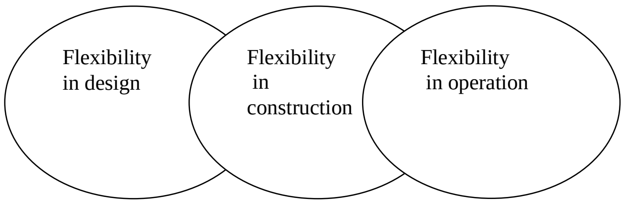

Fig. 1. Flexibility chain in construction industry

As can be seen from Figure 1, the assumption to adjust the scope of the project in the operation phase (gradual expansion) in response to the growing demand seems to be logically justified by long life cycle and the difficulty in predicting the performance requirements in term of 20-50 years. An example of this approach is the bridge of 25 April in Lisbon – fig. 2.

Fig. 2. Ponte 25 de Abril in Lisbon

This design and implementation in 1960. (in 1966 upper platform with 4 road lines, in 1998 6 road lines) survive until the continuation in 1990. (in 1999 the lower platform for 2 railway tracks), following the adoption of Portugal to the EU.

As already mentioned, flexibility can be applied at various levels of management: at the strategic level, tactical level and operational level (process), and in the different phases of the life cycle of a building (design, implementation and operation). Discussed later case study concerns the operational level in the construction phase – concreting of slab element at reduced temperature.

2.3 Principles of flexibility implementation

The simplified formula for the implementation of the flexibility includes seven steps:

1. Define the boundaries of the analyzed subsystem
2. Analysis of risks and uncertainties (key factors)
3. Identify environmental change scenarios
4. Generate flexible options, tactics and strategies
5. Analysis of the performance of the subsystem for different scenarios
6. Acceptance of the solutions (assessed on the basis of the adopted criteria)
7. The introduction of a flexibility in the system (including monitoring results).

Of course, in the case of non-acceptance of the solutions obtained (as a result of the simulation), one will return to the previous steps and find a better solution. Similarly, by observing the current results in the implementation must reckon with the possibility to modify the assumptions adopted to date (learning from examples).

Prior to the implementation one should identify key risks and uncertainties, and identifying the possibilities for observation, forecasting and control. Then one specify the feasible options, tactics and strategies of flexibility. It is extremely important on-line decision-making and effectiveness of their implementation. The flexibility implemented in the conditions of risk and uncertainty is leading to reduce the impact of negative phenomena and capitalize on the opportunities. One should pay attention to duality of flexibility. Two components can be distinguished:

1. Adaptability (active flexibility), which is the ability to respond rapidly to the predicted / observed changes. Besides predictability / observability process also requires the controllability
2. Robustness (passive flexibility), which only requires knowledge of changes in the environment of factor being analysed.

Although from the point of view of technical progress in the collection, transmission and processing of information and control seems to apply more favorable adaptability, but in practice the robustness is preferred due to its simplicity (of which may also be related to lower costs). Threat for the robustness strategy is to maintain a certain constant level of flexibility, which may indicate a risk of exceeding the required level of flexibility, or - even worse - non-compliance of this level to current requirements.

3 Case study

The present example concerns the operational level - concrete slabs at a gas station in a period of low temperature. It should be emphasized that the proper use of this flexibility in this case (the achievement of expected results - easy maturation concrete apron translates into effect at the tactical level (completion of projects on time) and strategic (profit for organization). Is also important for the reliability of a building (gas station) during operation. Otherwise - stop the process of curing and damage to the slab surface disqualify this important element of the building leading to the delay of the entire investment, contractual penalties and having to wait for favorable weather conditions (repair / rework). Figure 3 shows the destruction of the concrete structure from surface frost slab at the gas station.

Fig. 3. Frost destruction of the concrete slab surface at the gas station

Typical methods used during concreting under conditions of low temperature include:

1) overestimate of the quantity of cement in the concrete mix

2) heating the concrete mix

3) application of concrete admixtures

4) isolation of maturing concrete from the environment (thermal insulation).

In this case, the isolation of the concrete mix is difficult because of the special structure of the surface of the slab increasing adhesion and gas station equipment impeding access to the slab (petrol pumps, columns, and roof). Consequently, it is recommended that the use of a heated concrete mix and the concrete admixtures (options 2 + 3). Admixtures adopted it possible to achieve the necessary strength for frost resistance in a relatively short period of time (e.g. 48 h), however, does not protect against the effects of frost of concrete in the first hours of his maturation when the concrete has not obtained adequate strength, but the setting has already begun. Neville [33] indicates that if the concrete freezes immediately after placing, the setting does not occur and thus does not create the microstructure of the hardening concrete, which may be damaged by ice formation. If freezing occurs when the setting of concrete, but before it has acquired sufficient strength (resistance to frost 8-10 MPa), the expansion associated with ice formation causes destruction and irreversible loss of strength. The basic premise of the proposed method is focused on eliminating the risk of incorrect process flow of concreting resulting from the sudden short-term reduction in the ambient temperature (especially during the night), which may lead to the destruction of the concrete structure in the surface layer. The purpose of the addition of Phase Change Materials (PCM) is to maintain a positive temperature at the surface layer of the concrete despite on the risk of frost destruction (most risky is freezing of concrete at the beginning of maturation). In order to confirm the beneficial effects of applying a PCM in the case described were performed laboratory tests.

3.1. Laboratory tests

Laboratory tests were carried out in the refrigeration unit with the aim of simulating the conditions of placing of concrete on subsoil. The typical composition of concrete mix were used without the addition of PCM and followed with addition of 5.0% by weight of cement. The composition of the two mixes: without the addition of PCM and with PCM are shown in Table 1.

Table 1. Concrete mix composition

Component [kg/dm3]	**Without PCM**	**PCM 5%**
Cement	355	355
Sand 0/2 [kg]	669	545
PCM [kg]	0	124
Basalt grit 2/8 [kg]	593	593
Basalt grit 8/16 [kg]	696	696
Superplasticizer [kg]	2,46	2,46
Aeration admixture [kg]	0,35	0,35
Water [dm3]	158	158
Total	2473,81	2473,81

Analyzing the temperature in two concrete elements under the temperature falls below 0 ° C obtained results confirm the expected effects of the application of PCM (Fig. 4).

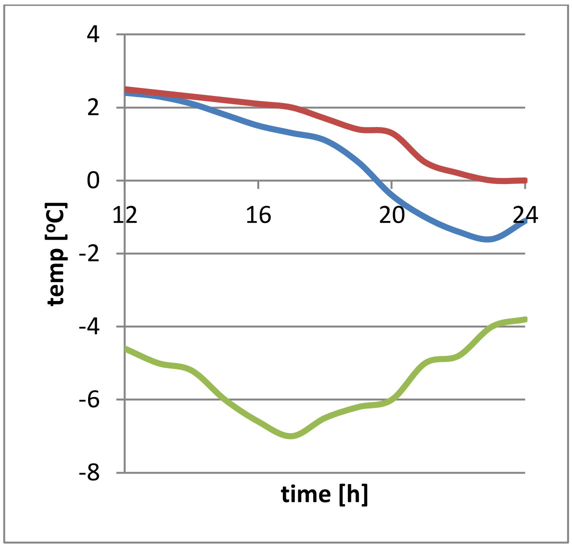

Fig 4. Temperature in concrete and environment (green – environment, blue – concrete without PCM, red – concrete with PCM)

The laboratory tests allow the formulation of rules concerning the use of Phase Change Material as the additive for concrete based on minimal ambient temperature and maximal time of temperature drop 9fig. 5). This type of rule will allow the selection of appropriate robust options based on the use of PCM as additive.

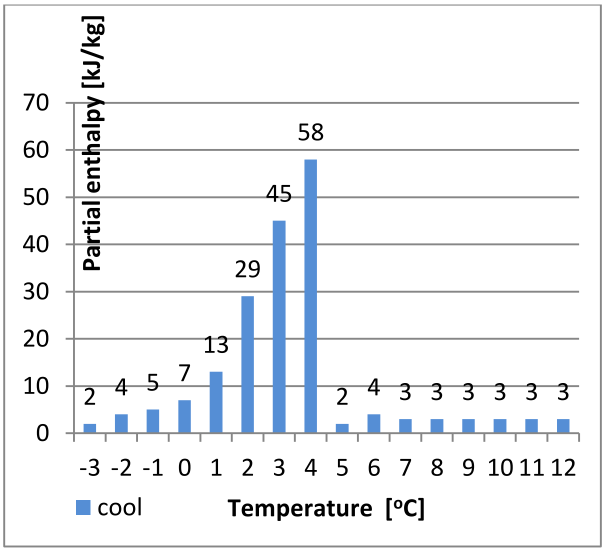

Fig. 5. Partial enthalpy distribution of PCM material [34]

Time [h] Temperature	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Concrete without PCM [ºC]	4,1	3,8	3,4	3,1	2,9	2,7	2,6	2,5	2,4	2,3	2,1	1,8	1,5	1,3	1,1	0,5	-0,4	-1	-1,2	-1,4	-1,1	-0,9
Ambiante [ºC]	1,6	1	-0,5	-1,5	-2	-3	-4	-4,3	-4,6	-5	-5,2	-6	-6,6	-7	-6	-5	-4,8	-4	-3,8	-3	-2	-2
Concrete with PCM [ºC]	5	4,4	3,8	3,4	3,1	2,9	2,7	2,6	2,5	2,4	2,2	2,1	2	1,7	1,4	1,3	0,7	0,3	0	0	0	0,1

Fig. 6. Monitoring of temperature of concrete (upper part)

3.2. Monitoring at the construction site

System of monitoring on the construction site is based on thermal imaging camera with the possibility of on-line transmission and air temperature sensors, and forecasting module. The applied the camera allows to set temperature limits initiating signal (email, SMS) and based on it to run the appropriate action. Environmental monitoring is based on: 1) the projection on-line from two independent sources, 2) measured on site using sensors disposed in the surroundings of concreting element, and 3) scan the surface temperature of this concrete slab.

Multifunctional infrared camera was used.

Thermal image was recorded with high resolution of 288 pixels × 384 (more then 110 000 measuring points). Work facilitates of the built-in laser pointer and a video camera (1600 × 1200 pixels) with a microphone and speaker.

The camera of this type allows to preview online through a computer with access to the Internet or GSM card. Typical image from this camera is given on fig. 7.

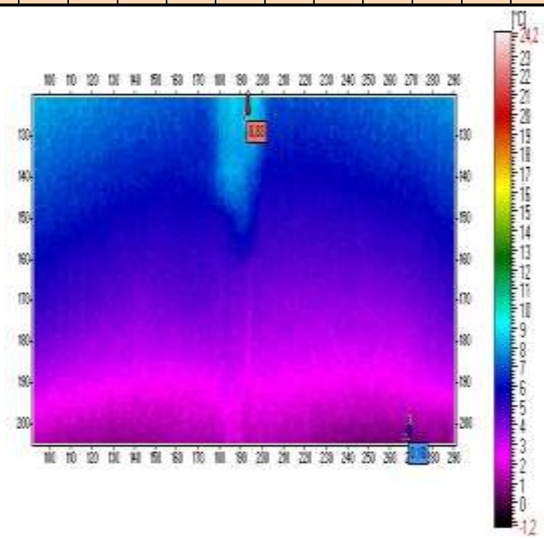

Fig. 7. Example of camera shot with monitoring of thermal conditions

The described system can be used for control of adaptation options (heating of the concrete), but in this case serves to confirm the correctness process flow of curing. The use of classical adaptation strategies is presented in an earlier article [35].

4 Conclusions

The analysis of literature, the theoretical basis and discussed examples allow to draw the following general conclusions:

1. Flexibility seems a method in construction management for efficient and effective action in conditions of risk and uncertainty. Application of flexibility in deterministic conditions is pointless.
2. Flexibility allows to limit the impact of negative phenomena and increases capitalize on the opportunities.
3. Flexibility can be used at different stages of the life cycle of a building (it creates a chain flexibility), and at different levels of management
4. In the case of typical application of strategic level flexibility involves a multi-step process that allows the gradual expansion of investment in response to the growing demand (of course it is also possible to predict the reduction in demand - e.g. in the case of sports facilities after the Olympic or continental competitions). In this case, the criterion is the net present value (NPV).
5. Application of flexibility at the strategic level shall be assessed by investor / user of the object
6. The basic level of application of flexibility for the contractor of construction processes is the operational level
7. A typical application of flexibility at the operational level is to adjust the execution options to environment.

In relation to the presented case study it can be concluded that:

8. Additive PCM to the maturing concrete at low temperature reduces the risk of frost damage of the top layer of slab
9. It is essential to apply robustness "embedded" in the process by modifying the material (concrete).
10. The presented strategy of action is intended to quality assurance of concrete maturing at low temperature with risk of short-term temperature drop.

The presented operation strategy is based on two robust strategies: 1) to provide a relatively short period of time to achieve the frost resistance by using hot concrete mix and admixtures and 2) ensure the proper conduct of the concrete curing process, despite the risk of periodic sudden drop in temperature below zero thanks to the addition of PCM. The monitoring system on the site is intended primarily to confirm the correct process flow, and not run adaptation strategy (heating of the concrete), which is difficult to implement in the case described.

Acknowledgements

The authors acknowledge support from statutory research funds DS at the Institute of Structural Engineering Poznan University of Technology

References

[1] Pachon A.G and Jacob J.-F. Necessity of a Disruptive Change in The Construction Industry – analysis of problematic situation. In *Proceedings of the CIB*IAARC W119 CIC 2013 Workshop "Advanced Construction and Building Technology for Society*, pages 1-13, Munchen, Germany, 2014.

[2] Berlin-Brandenburg-Airport. On-line: http://berlin-brandenburg-airport.com/Airport/History.html, Accessed: 24/01/2015

[3] Central Artery/Tunnel Project (CA/T) On-line: http://www.massdot.state.ma.us/highway/thebigdig/projectbackground.aspx Accessed: 24/01/2015

[4] Modlin air port. On-line: http://www.modlinairport.pl/lotnisko/o-lotnisku-2/kalendarium.html Accessed: 26/01/2015

[5] Kaplinski O. *Balancing of cyclical construction processes using stochastic approach* [in Polish], Series: Dissertations No. 91, Poznan University of Technology Publishing House, Poznan 1978

[6] Kaplinski O. Diminishing non-uniformity of construction processes, *Construction Management and Economics*, 11(1):53-61, 1993

[7] Reichelt U. Einsatz flexibler Fertigungssysteme in der Betonindustrie, *Betontechnik*, 8:75-77, 1987

[8] Halpin D.W. Adaptation of flexible manufacturing concepts to construction. In *Proceedings of the 4th International Symposium on Robotics and Artificial Intelligence in Building Construction*, Haifa, Israel, pages 704-717, 1987

[9] De Neufville R. Dynamic strategic planning for technology policy, *International Journal of Technology Management*, 19(3/4/5):225-245, 2000

[10] De Neufville R. *Uncertainty management for engineering systems planning and design*, Faculty Monograph, MIT Engineering Systems Symposium, Cambridge, MA

[11] Walker D., Shen J. Project understanding, planning, flexibility of management action and construction time performance: two Australian case studies, *Construction Management and Economics*, 20(1):31-44, 2002

[12] Walker D., Loosemore M. Flexible problem solving in construction projects on the National Museum of Australia project, *Team Performance Management*, 9(1/2):5-15, 2003

[13] Thomas H.R. Schedule acceleration, work flow and, labor productivity, *Journal of Construction Engineering and Management*, 126(4):261-267, 2000

[14] Thomas H.R., Horman M.J., de Souza U.E.L., Zavirski I. Reducing variability to improve performance as a lean construction principle, *Journal of Construction Engineering and Management*, 128(2):144-154, 2002

[15] Thomas H.R., Riley D.R., Sanvido V. Loss of labor productivity due to delivery methods and weather, *Journal of Construction Engineering and Management*, 125(1):39-46, 1999

[16] Thomas R., Horman, M.J. Fundamental principles of workforce management, *Journal of Construction Engineering and Management*, 132(1):97-104, 2006

[17] Thomas H.R., Sanvido V. Role of the fabricator in labor productivity, *Journal of Construction Engineering and Management*, 126(5):358-365, 2000

[18] Olsson N.O.E. Management of flexibility in projects, *International Journal of Project Management*, 24(3):66-74, 2006

[19] Mayer Z., Kazakidis V. (2007) Decision making in flexible mine production system design using real options. *Journal of Construction Engineering and Management*, 133(2):169-180

[20] Saari A., Kruus M., Hamalainen A., Kiiras J. Flexibuild – a systemetic flexibility management procedure for building projects. *Facitily*, 25(3/4):104-114

[21] Perminova O., Gustafsson M., Wikstrom K. Defining uncertainty in projects – a new perspective, *International Journal of Project Management*, 26(1)73-79, 2008

[22] Paslawski J. Flexibility implementation in construction process engineering, In *Proceedings of the the 25th International Symposium on Automation and Robotics in Construction*, pages 610-615, Vilnius, Lithuania, 2008

[23] Karlowski A. Telemetric system for management in concrete process, In *Proceedings of the the 25th International Symposium on Automation and Robotics in Construction*, pages 318-323, Vilnius, Lithuania 2008

[24] Paslawski J. Flexibility in highway noise management, *Transport*, 24(1):66-75, 2009

[25] Paslawski J. Hybrid flexible approach for Six Sigma implementation in constructional SME, *Journal of Civil Engineering and Management*, 19(5):718-727, 2013

[26] Shahu, R., Pindur A. K., Ganapathy, L. An empirical study on flexibility: a critical success factor of construction projects, *Global Journal of Flexible Systems Management*, 13(3):123-128, 2012

[27] Falwett W., Hughes M., Krieg H., Albreht S., Vennstrom A. Flexible strategies for long-term sustainability under uncertainty, *Building Research and Information*, 40(5):545-557, 2012

[28] Hajdasz M. Flexible management of repetitive construction process by an intelligent support system. *Expert Systems with Applications*, 41(4 part 1):962-973

[29] Lawrence, P.R., Lorsch, J.W. *Organization and Environment: Managing Differentiation and Integration*. Boston, Massachusetts: Harvard University, 1967

[30] Volberda H. *Building the flexible firm. How to remain competitive*, Oxford University Press, 1998

[31] Ashby W. R. *An introduction to cybernetics*, Chapman& Hall, London, 1956

[32] Kozminski A., Jemielniak D., *Management the basics* [in Polish]. 2nd Ed., Wolters Kluwer Poland, Warsaw 2011

[33] Neville A. M. *Properties of concrete*. 5th ed. Prentice Hall, Pearson, San Francisco, 2012

[34] Rubitherm technical data. On-line: http://www.rubitherm.de/english/download/Techdata_%20RT4_EN.PDF Accessed: 27/01/2015

[35] Karlowski A., Paslawski J. Monitoring of construction process in the variable environment, *Technological and Economic Development of Economy*, 14(4):503–517, 2008