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MODELLING CONSTRUCTION PROCESSES: A REVIEW OF RESEARCH AND DISSERTATIONS AT THE POZNAŃ UNIVERSITY OF TECHNOLOGY

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The achievements, grants and awards presented to the Chair of Construction Engineering and Construction Management at PUT in the field of modelling of construction processes are reviewed in the article. The needs of phenomena analysis (e.g. waiting, equilibrium), use of the induction method and an application of hybrid methods have been indicated in the review of the problems and modelling methods. Selected areas, mainly of research published abroad by our authors, have been analysed among other publications in context of discussion of research areas.

Keywords: construction management, construction engineering, modelling of processes, application of mathematical methods, hybrid methods

1. INTRODUCTION

Problems of construction processes modelling at Poznań University of Technology are an area of responsibility of the Chair of Construction Engineering and Construction Management (CE&CM), and have had a long standing tradition. The first essential item in the field was a book devoted to network planning [43][1]. Ph.D. thesis by the author of this paper (c.f., Table 2), awarded by the Ministry, containing a description of the first research and applications of the

[1] This book was awarded by The Ministry of Higher Education, Science and Technology. Prof T. Biliński was the reviewer of the first edition.

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queue theory[2]. Another essential item was the monograph [69] - also awarded by the Ministry.

In our research work, we have formalised the following rules:
From the scientific point of view, modelling of construction problems should be performed in accordance with the phenomena analysis. Two basic groups of the phenomena in question are presented in monograph [69]. These are, for example, waiting and equilibrium phenomena. Many research papers and dissertations have been generated within their context.

The application of modern modelling methods, including combined/hybrid methods, methods based on artificial intelligence, including expert systems (ES), and acquisition of knowledge in particular, drew attention to the methodology, i.e. to the need of using the induction method.

The method, based on precise formulation of general conclusions from detailed premises, is more labour consuming, and requires data to be obtained and checked in stages. The absence of this method in analyses serving investment and economic policies in post-communist countries has had long-term negative consequences. One of the fundamental reasons of failure in the use of modelling in the construction practice was the fact that the induction method was not used. Even today, young "experts" who want to obtain the effect of application of mathematical programming or ES too quickly, make the same mistake and use the deductive method.

The relationship between induction and knowledge bases, in the context of heuristics rules, is presented in Figure 1.

2. REVIEW OF THE PROBLEMS AND MODELLING METHODS

Mathematical statistics, theory of probability (including application of stochastic processes) and linear programming were first investigative tools. Traditionally, the strongest trend in research was modelling and organisation of construction processes, including the application of computers and artificial intelligence. The survey of all those problems, a synthesis of the research, and guidelines - also for prospective Ph.D. students - have been presented in a monograph publication entitled *„Modelling of construction processes. A managerial approach”* [69].[3]

[2] The dissertation was presented at the time when Prof R. Świtka was the dean of the Civil Engineering Faculty of PUT in Poznań.

[3] Prof. O. Kapliński's book was awarded a special award in the Building and Construction Department 1998 competition at the Ministry of Administration and the Interior. This book is intended for designers and contractors as well as for students, scientific workers of Civil

Network methods have played an important role in modelling construction processes. This fact is due to:

- applicability in management projects consisting of processes, thanks to alternative solutions,
- good software.

Network methods are among the most common techniques used in CM. Thanks to spreadsheets, their utility has increased even further. Accordingly, network planning combined with cash flow was one of the projects implemented under the author's supervision – c.f. Ph.D. thesis in Table 2 (submitted by T. Wiatr).

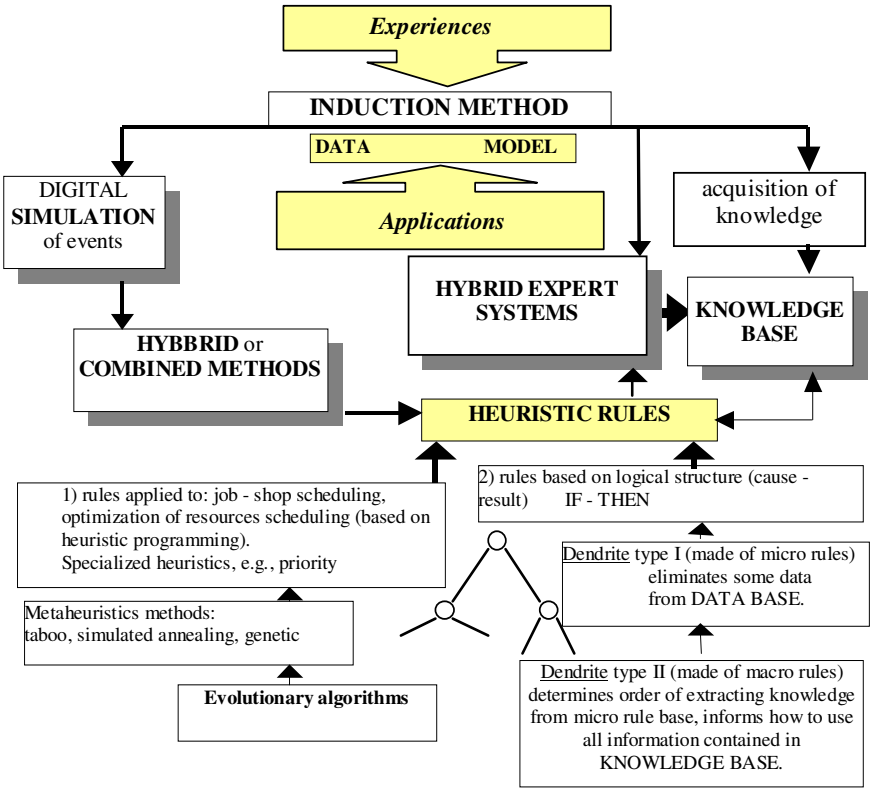

Figure 1. The significance of induction in modeling of construction processes

Engineering Faculties, particularly for students working on dissertations in the field of Construction Engineering and Management.

The background and context of our considerations is based on relations between a model and its original. Special attention has been put on principles of organising production processes in the construction industry. Two complementary modelling systems have been suggested: **T**echnology - **M**odel - **T**echnology (**T-M-T**) and **I**nvestigations - **S**imulation - **I**nvestigations (**I - S - I**). This type approach has been used in our research and in many publications (c.f., [3, 4, 52, 62, 68. 69].

Of course, the development and applications of decision aiding and modelling techniques in construction management were compared with achievements abroad. Three fundamental groups of methods were taken into consideration: analytical, heuristic and simulation. More attention was dedicated to the computer building representational approach (including expert system) as well as to the management conditioning system. Issues mentioned here were developed in the following books, articles and papers - c.f., [1, 55, 69].

The efficient organisation of construction processes and an adequate balancing of these processes require appropriate measures in order to assess the feasibility of their implementation. This assessment has been made using entropy, dispersion, non-uniformity and the availability coefficient. Two types of distribution which can be met in the organisation of production have been identified: distribution of work time, and distribution of production volume (characterised by opposite skewness).

The occurrence of non-uniformity in construction industry production processes is frequent. An outline of a formal approach making use of the theory of stochastic processes and statistics has also been made. Attention has been drawn to necessary and satisfactory conditions for balancing these processes. The author distinguishes between the distribution of work time and distribution of production volume. The diminishing of non-uniformity is possible as a rule, i.e., there must be mutual relations between the intensity of processes, concentration (superposition) of the processes and their non-uniformity. The first examples of superposition of processes (as a case of production concentration) have been presented during the CIB Congress [64]. Attention was paid to a reduction of expenditure resulting from the actions mentioned above. Application of these methods often requires quite simple technical or organisational steps.

The analysis of waiting phenomena is the essence of many dissertations, grants and papers. Methods of interpretation of these phenomena from the viewpoint of two types of events (homogeneous and heterogeneous) are presented in Figure 2. The left part of Figure 2 refers to the results of investigations on the influence of the dispersion and structure of a system on the efficiency of production systems (application of queue theory). The right part of Figure 2 illustrates a method for investigating and evaluating reliability which is described in the context of proper work distribution within the system. Ways of increasing reliability have been used while comparing redundancy with systemic inertia which may

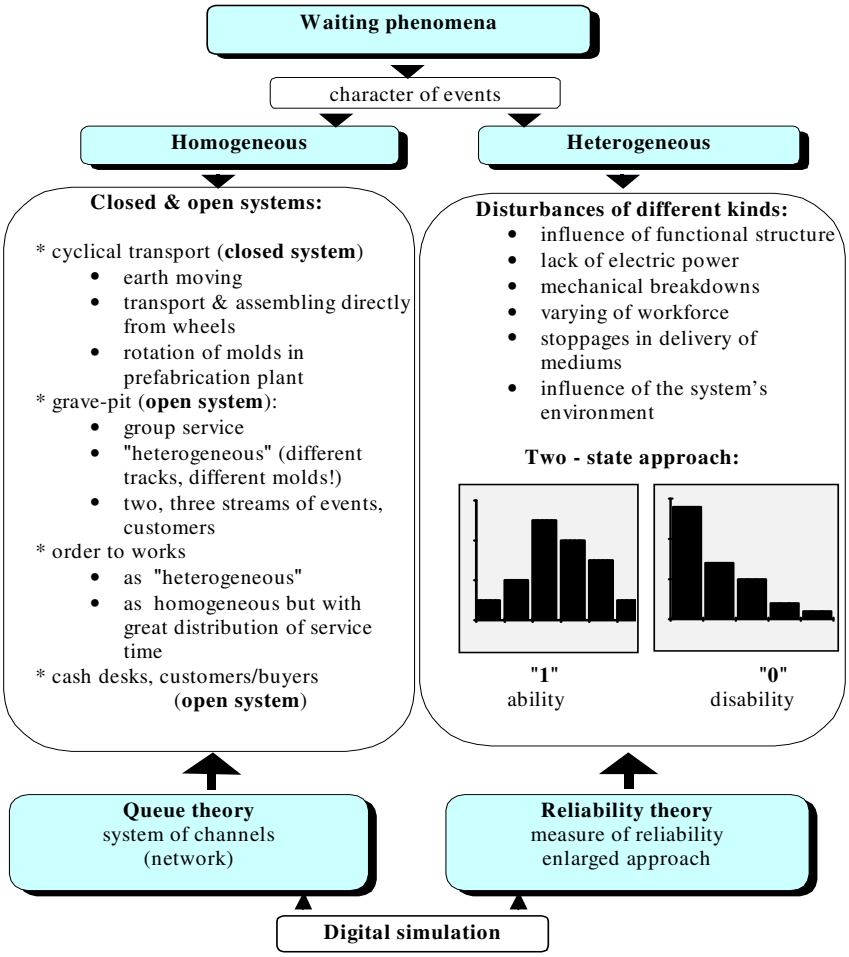

Figure 2. Two groups of events in waiting phenomena

occur, for example, during the prefabrication of concrete elements. Generally, problems of reliability determine most spectacular successes of our Chair.

So-called combined methods have gained special significance, since "pure" methods, i.e., operational research (OR) or digital simulation, or heuristic methods are, in some cases, insufficient in view of the requirements of organisation and control. In specific situations, combined methods are more adequate. Generally, combined methods result from a fusion of two or more classical

methods, i.e., analytical simulations or heuristic simulation methods. Two additional remarks seem to be appropriate here:

- combined methods can and should be used to create so-called hybrid expert systems;
- graduate dissertations, particularly those pertaining to production control, without the application of combined methods prove to be much lower level, and their applicability is greatly reduced.

A specific approach to the problems of production process balancing has been used in dissertations more than anywhere else (c.f., Table 1 and Table 2). The approach was based on an analysis of equilibrium phenomena. Discontinuity phenomena were interpreted from the viewpoint of the catastrophe theory. The usefulness of studying the problems of catastrophic systems transformations while analysing the effectiveness of the functioning of technological lines has been pointed out. The methodology of balancing in unspecified conditions was also discussed. In order to present this methodology, a computational tool, based on infinite strategic games, has been used.

Alternative solutions are very important in development and application of decision techniques in construction management. Consequently, multi-criteria optimisation (as a decision support system) is the essential subject of the research in our Chair. A selection of the best solutions using the ENTROPY Method was a first uses of the MCDA optimisation. On the basis of the sensitivity analysis carried out in the framework of this method - the factors of influence of the form of data input, the evaluation scale and the weights on the value vector have been examined. Later, a basic classification methodology related to multi-criterial decision making has been proposed. Interesting theoretical and practical results have been achieved in co-operation with Lithuanians. Dr. T. Thiel's dissertation is significant in this field (c.f., Table 2).

Expert Systems was a domain the nineties when we saw the attempt of an application of expert systems in the design of construction items.
Special attention has been paid to the structure of knowledge base. Two categories of knowledge have been distinguished within the structure of an expert system: micro - knowledge on the principles of construction technology, and macro - knowledge on the art of design. This discussion included the example of applying an expert system to monolithic construction technology - c.f. the dissertation submitted by M. Hajdasz (Table 2).

Further consideration was based on the hypothesis that the scope of applications of "pure" expert systems, particularly those of the construction industry, will be limited. Instead, so-called Hybrid Expert Systems were suggested. Three levels of solutions to the problem have been suggested:

- the classical methods level,
- the combined methods level,
- the hybrid expert systems level.

Combined methods are the ones which result from the fusion of two or more classical approaches. A hybrid expert system is that which takes into account at least one of the combined methods.

A synthesis of the research and modelling methods is presented in the above mentioned book [69]. Of course, the book does not cover all methods which are and should be practical in CM. Nonetheless, one of the problem areas of this book is its obviously difficulty in dealing with specific problems to be solved, which most often results from unique practical needs and requirements. The author's intention has been to point out and search for mechanisms, e.g., those of distortion and its elimination, modelling phenomena, ways of delivery of numeric data for decision making, etc.

From the practical point of view, the different modelling methods in the Civil Engineering (CE) and Construction Management (CM) can be reduced to three fundamental groups:

1. analytical,
2. heuristic,
3. simulation.

At present, we are most experienced in the use of methods from the first group. It follows from the author's personal experience in the use of these methods in the building industry, that linear models tend to oversimplify modelled problems. Development of microcomputer technology favours the application of non-linear programming methods. The existing relations between production and costs or company profit confirm the belief that it is purposeful to formulate such non-linear tasks. What should also be mentioned is the so-called mixed programming, i.e., mathematical programming with logical conditions. Problems of this type are often encountered in construction practice, and are not taken into account in the modelling process. A similar situation occurs in the case of programming in integers (including binary programming) which is especially useful in problems of production control, selection of work crews, scheduling, etc.

The following conclusion can be drawn on the basis of experience gained so far: all practical tasks in the field of CM – when correctly formulated - take the form of a non-linear task with a limited set of permissible solutions.

3. ACHIEVEMENTS, GRANTS AND AWARDS

Methods presented above based on development of variety of themes over a number of years. One of them was the theme of monolithic construction. The dissertation presented in Table 1, manuals (c.f. [96]) and awards were an effect of this activity. Two characteristic awards can be distinguished:

- The individual award of the Minister of the Building and of the Industry of Builder's Materials for the elaboration and practical application of the system of the monolithic construction SBM (1980, A. Skarzyński),
- The joint award of the Minister of the Higher Education, Science and Technology granted for success in the sphere of research in the range of the technology of concrete – work done on monolithic construction (1980, manager: A. Skarzyński).

The optimisation in production of prefabricated elements of different building systems has dominated our Chair for several years. In effect, we have had numerous publications, and two Ph.D. theses, mentioned in Table 2.

The technology and organisation of construction of water supply systems and sewage systems in rural areas dominated in 1987-1991 (manager: O. Kapliński).

Two grants of Department IV of Polish Academy of Science in the field reliability of production for construction industry (manager: O. Kapliński) initiated the development of new investigative methods. Two themes have been developed:

- The algorithmisation of the reliability control of technological lines in construction industry (with organisational and economic aspects), 1978-1980,
- The designing of technological lines with application of reliability and equilibrium phenomena, 1981-1983.

The subject: “Methods of automatization of management and control of technological processes in construction industry” developed in the framework of inter-department problem of Ministry of the Higher Education, Science and Technology and Polish Academy of Science (1983, manager: O. Kapliński) has been awarded a joint prize.

Prof. O. Kapliński has been granted the individual scientific award of Polish Academy of Science - Department IV (1980).

J. Brzeziński has been awarded for a winning paper entitled "The Spirit of Innovations. Chances and Threads", during the International Management Symposium in St. Gallen, Switzerland, 1996.

Additionally, Prof. O. Kapliński has been honoured by a nomination in the competition of The Foundation of the Polish Science (FNP) in the programme under the heading: Subsidies for scientists (2001), thanks to which a new theme for the Chair has been identified, namely: Advisory systems operating under uncertainty conditions in construction industry with the application of evolutionary methods. The investigative area is: Management of investments under uncertainty conditions.

The subject „Problems and methods of real estate estimation”, started in eighties and nineties, has been later transformed into a course for postgraduate students. The course is offered until today (manager: Prof. A. Skarzyński).

The Chair participates in spectacular across-the-border co-operation between three academic centres from Germany, Lithuania and Poland. Two colloquia have been organised by the Chair in 1993 and 2003. The theme of development of a decision making support system dominated during the last colloquium (2003, chaired by Prof. O. Kapliński). Additionally, verbal decision methods, e-business systems, risk in property valuation methods, investment processes in construction were presented. History and evolving trends of nine colloquia has been presented in [48, 100].

4. REVIEW OF DISSERTATIONS

Two kinds of dissertations are considered: Ph.D. theses and post-doctoral dissertations (habilitation thesis). They are taken down in two tables.

Theses listed in Table 1 cover the wide spectrum of research and modelling of construction processes.

Table 1. Post-doctoral dissertations (in Polish)

Author	**Title**	**Publishing house, series, year**
Piórecki S.:	Investigations of work time and the influence of its dispersion on production efficiency in construction industry	Poznań University of Technology Press, Dissertations Nr. 59, Poznań 1973.
Kapliński O.	Balancing of cyclic construction processes (stochastic approach)	Poznań University of Technology Press, Dissertations No. 91, Poznań 1978.
Jasiczak J.	Criterions of control of stabilization concrete compressive strength determinate by the probabilistic methods	Poznań University of Technology Press, Dissertations No. 271, Poznań 1992
Skarzyński A.:	Technological and organizational principles of the realization of the multistory monolithic concrete building in the climbing forms	Poznań Univ. of Technology Press, Dissertations No. 263, Poznań 1992

Table 2. Selected doctoral dissertations (all in Polish)

Author	Theme	Year	Supervisor	Method/ theory
Skarzyński A.	Criteria of optimal selection of machines and equipment for delivery of components, productions and transportation of the concrete – mixture	1968	Rowiński L.	Linear programming
Kapliński O.	Optimization of technological lines in assembly process directly from vehicles (prefabricated houses from concrete elements)	1971	Stefański A.	Queue theory
Jasiczak J.	The capacity of storage yards of elements in the prefabrication plants: The methodics of settlement of the capacity	1979	Stefański A.	Theory of probability
Pawlicki D.	Research of the inequality of the assembly of prefabricated flat buildings	1980	Stefański A.	Econonometrics
Borucka E.	Method of investigation and estimation of production system reliability (in concrete prefabrication)	1982	Kapliński O.	Reliability theory
Meszek W.	Balancing of construction processes under unspecified conditions	1989	Kapliński O.	Games theory
Celińska M.	Programming of concrete-mix plant location with regard to a proposed method of demand dimension determination	1990	Kapliński O.	Non-linear & dynamic programming
Zakrat M.S.	The influence of inertia on the reliability of technical systems as exemplified by the production of building materials	1992	Kapliński O.	Reliability theory
Pasławski J.	Choice of accelerated concrete maturity cycle parameters based on process' simulation	1994	Tomkowiak K.	Digital simulation
Thiel T.	Methodological aspects of multi-criterion decision aid in civil and construction engineering	1997	Kapliński O.	MCDA optimization
Hajdasz M.	Rule-based knowledge in the system supporting the design for building grain silos erected by the slip method	1998	Kapliński O.	Artificial intelligence, expert system
Wiatr T.	Control of construction projects in aspect of financial strategy	2003	Kapliński O.	Network methods, simulation, cash flow

They originate from the field of the construction processes mechanisation, explanations of disturbances in the workflow, reliability and efficiency of processes, decision-making of rational solutions and attempts of utilising artificial intelligence.

The last Ph.D. thesis entitled *Control of construction projects in aspect of financial strategy* was presented in December 2003 (Author Dr. T. Wiatr). The research problem was predicting project cash flow with relation to network schedule of construction project. The foundation of the problem solving was a synthetic representation of the project in the form of primary and secondary functions. These functions are elements of original IVO model (Input Value Output), and can be compared to a tool used in cost/schedule integration.

Earlier, two other dissertations, presented by Dr. T. Thiel and Dr. M. Hajdasz, ware granted an award in the Building and Construction Department competition at the Ministry of Administration and the Interior.

Two Ph.D. theses are being developed at present:

- Management strategies in the full time of the whole life cycle of a flexible road pavement. This dissertation discusses the problem of the life-cycle cost analysis in flexible pavement, Author: A. Fojud from the Chair of CE&CM,
- Multi-factor modelling of labour consumption and cost of assembly of flexible corrugated steel structures, Author: L. Janusz, from ViaCon-Polska.

Members of the Chair working at present on post-doctoral dissertations:

- J. Pasławski, on the advisory system, including the application of hierarchical model, on the example of concreting,
- T. Thiel, on the MCDA optimisation, on the example of public and industrial buildings maintenance,
- W. Meszek, on the measurement of risk error in determination of market value of real estate,
- M. Hajdasz, on intelligent methods at building site, including the application of chaos theory.

5. REVIEW OF PUBLICATIONS

The total number of publications of our Chair in the field modelling of construction processes is over 300. They have been published in the following languages: Polish, German (in: GFR, GDR, Lithuania), English (in: Holland, the USA, Egypt, Israel, Yugoslavia, Great Britain, Australia, Singapore, France, Switzerland, Lithuania, Czech Republic, Hong Kong), Russian (in: USSR, Yugoslavia, Czechoslovakia, GDR), Serbo-Croatian (in Yugoslavia), Ukrainian (in USSR), French (France, Poland, Portugal, Rumania, Slovak Republic), Czech and Lithuanian.

In the References section, only selected items published abroad have been presented. They cover following areas of research:

- Modelling technological processes, production of building materials, construction of buildings: [2, 20–26, 88, 89, 96],

- Development and application of decision modelling techniques (including trends in evolution of ideas, quality data): [7, 42, 46, 48, 49, 55, 57, 62, 69, 77, 86, 92, 100],
- Network methods, network planning, cash flow: [1, 38, 43, 99],
- Organisation of construction processes, balancing, scheduling, distributions, non-uniformity: [5, 56, 60–62, 64, 66, 67, 69, 70],
- Waiting phenomena, evaluating reliability, inertia, efficiency of production systems, queue theory: [3, 5, 34, 39, 50, 58, 60, 66, 69–72, 74, 75, 79, 80, 93],
- Equilibrium phenomena, strategic games, discontinuity phenomena, catastrophe theory: [30–33, 37, 40, 41, 67, 69, 84],
- Modelling and training in the field of applicability and feasibility: [52–54, 63, 65, 69, 77],
- Alternative solutions, multi-criteria optimisation: [1, 35, 36, 44, 45, 69, 82, 83, 97, 98, 102],
- Artificial intelligence, expert systems: [6, 19–21, 28, 29, 47, 51, 68, 69, 74, 78, 81, 101],
- Simulation and combined methods (labour efficiency, accident rate, simulators, labour-consumption): [3–5, 27, 28, 50, 51, 58, 59, 68, 69, 73, 74, 78],
- Advisory systems in processes of concreting and road management: [16, 85, 87, 94],
- Modelling of investment process, whole life cycle: [9, 15, 18, 35, 38, 45, 86, 90, 103],
- Modelling of transport network, location problems: [8, 10, 12–14, 17, 98, 102],
- Management strategies, risk management [9, 11, 15, 16, 18, 76, 82, 83, 89–93, 95].

6. ANTICIPATED RESEARCH

The following methods should be developed and practically implemented in the nearest future:

- Digital simulation of events,
- Development and applications of heuristic algorithms and metaheuristic methods, in this: searching through the taboo, simulated annealing, genetic algorithms (c.f., Figure 1),
- Evolutionary methods (algorithms),
- Advisory systems, Contingency (dependence on qualitative data) and application in risk management. It is predicted that System Engineering of Construction Projects will be the basic investigative problem, including different

cases (conditions), such as: the issues of hierarchy of resources, the phenomenon of hierarchy of performers, the hierarchy of criteria (of decisions and optimisation).

7. CONCLUSIONS

Reports, dissertations and publications of the Chair of Construction Engineering and Construction Management at Poznań University of Technology represent good professional level and have been highly praised.

Hybrid methods are the future and a universal tool for the solution of complex problems which surface in CE&CM.

Problems of modelling of construction processes are based on the decision techniques, first of all on the theory of rational decisions (TRD). It clearly constitutes a supplement to formulating and solving practical problems using the ideas drawn from the adaptational decision theory (ADT).

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MODELOWANIE PROCESÓW BUDOWLANYCH: PRZEGLĄD BADAŃ ORAZ DYSERTACJI REALIZOWANYCH W POLITECHNICE POZNAŃSKIEJ

S t r e s z c z e n i e

Artykuł przedstawia osiągnięcia, tematy badań oraz nagrody Zakładu Technologii i Organizacji w Budownictwie Politechniki Poznańskiej z zakresu modelowania procesów budowlanych. W ramach przeglądu problemów i metod badawczych zwrócono uwagę na potrzebę analizy zjawisk (np. równowagi, oczekiwania), konieczność stosowania metody indukcji oraz szerszego wykorzystania metod hybrydowych. Wskazano obszary badań oraz dokonano przeglądu publikacji pracowników Zakładu – głównie obcojęzycznych.