

16-17 November, Novi Sad, Serbia



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Novelty
Design
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Sustainability

Proceedings

Editors: M. Trivunić, I. Džolev, M. Šešlija

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iNDiS 2023

Department of Civil Engineering and Geodesy, Faculty of Technical Sciences, University of Novi Sad, is organizing the sixteenth international scientific conference "iNDiS 2023" - integration, novelty, design, interdisciplinarity, sustainability. From this year, the modified format of the event starts, therefore the conference will be held biennial in the future.

Topic of the first conference, held in 1976, was "Industrial construction of apartments" because of its modernity in that period. Later, conferences were held with a considerably broader theme of "Construction Industrialization", and soon papers from all areas of construction appeared at the conference, from urban planning and design of buildings of various purposes, to maintenance and major interventions on the built construction stock. This led to the expansion of the area of expertise, covered by this conference, in which, in addition to civil engineers, urban planners, architects, engineers of other professions, who work in construction, sociologists, economists and others participate.

This conference, like several previous ones, covers the problems of planning, designing, construction and renovation of construction, geodesy, geoinformatics and risk management of catastrophic events, which have come across to an adequate response from researchers and engineers of various profiles, both from our country and abroad.

Members of the International Scientific Committee actively participated in the preparation of the conference, both as reviewers and authors. It is expected that the presentations of papers and discussions at the conference will enable the definition of the main directions of construction development, in accordance with modern trends, since many ideas and results, experimental and theoretical researches in the fields of construction have been promoted.

For this conference, the Proceedings consists of two books, namely Book 1. Papers in English and Book 2. Papers in Serbian, which enables better and more fruitful communication and exchange of experiences with colleagues from abroad.

Additionally, the possibility of establishing new and strengthening existing professional and collegial ties is also of the great importance. This year, authors from 13 countries are participating in the Conference, and the Proceedings Book 1 contains 94 papers in English, while the Book 2 contains 23 papers in Serbian, in total 117 papers.

The editors express their sincere gratitude to all the authors for the effort invested in writing the papers as well as for their contribution to this event.

Editors of the Proceedings

CONTENTS

PLENARY LECTURES

Dragana Konstantinović ENCLOSED CITY CENTRE APPROACH AND DESIGN METHODOLOGY FOR RECONSTRUCTION OF "SPORTS AND BUSINESS CENTRE VOJVODINA"	14
Zoran Matijević MANAGEMENT OF MAJOR INTERNATIONAL PROJECTS	16
Aleksandar Pavić IS FLOOR VIBRATION SERVICEABILITY PROBLEM SOLVED FOR GOOD BY EMERGENCE OF COMMERCIAL ACTIVE MASS DAMPERS?	45
Sergio Ruggieri, Andrea Nettis, Mirko Calò, Alessandro Nettis, Angelo Cardellicchio and Giuseppina Uva TOWARDS A NEW VISION OF CIVIL ENGINEERING: DIGITAL INNOVATION APPLICATIONS FOR THE STRUCTURAL HEALTH MANAGEMENT OF EXISTING BRIDGE PORTFOLIOS	55
Luka Zevnik DIGITAL CONCRETE: FROM TECHNOLOGIES TO MATERIALS	68

CIVIL ENGINEERING

Maja Ranisavljević and Jelena Dobrić EXPERIMENTAL RESPONSES OF COMPRESSED I-SECTION SHORT COLUMNS WITH WEB OPENINGS	70
Ksenija Tešić, Ana Baričević and Marijana Serdar ASSESSMENT OF CONCRETE STRUCTURES USING GROUND PENETRATING RADAR: MAIN FINDINGS OF THE ASAP PROJECT	80
Srđan Nikačević and Ivana Kovačić METASTRUCTURES WITH A SINGLE VIBRATION ABSORBER: HOW TO DESIGN IT AND WHERE TO LOCATE IT TO ACHIEVE BROADBAND VIBRATION ATTENUATION?	87
Tomaž Žula, Stojan Kravanja and Primož Jelušič MAXIMIZING PROFIT THROUGH SUSTAINABLE OPTIMIZATION OF SIMPLY SUPPORTED BEAMS	98
Marija Nefovska-Danilović and Vitomir Racić VIBRATION SERVICEABILITY ASSESSMENT OF A STRESS-RIBBON FOOTBRIDGE	103
Marijana Vujinović, Đuro Krnić, Mehmed Batilović, Vladimir Bulatović and Zoran Sušić APPLICATION OF TERRESTRIAL LASER SCANNING TECHNOLOGY IN THE PROCEDURE OF CREATING AS-BUILT PROJECTS OF OBJECTS	111
Violeta Mircevska and Ana Nanevska IMPACT OF THE IMPERMEABLE LINING OF TAILINGS RESERVOIR TO THE HYDRODYNAMIC INSTABILITY OF TAILINGS DAM	122
Ana Nanevska and Violeta Mircevska FINITE ELEMENT MODELING AND SEEPAGE ANALYSES TO ASSESS THE HYDRODYNAMIC EFFECTS OF TAILINGS DAMS UNDER DIFFERENT SEEPAGE CONDITIONS	130
Đuro Krnić, Marijana Vujinović, Mehmed Batilović, Marko Marković and Tatjana Budimirov INVESTIGATION OF OBJECTS VERTICALITY USING TERRESTRIAL LASER SCANNER	141
Milka Šarkanović Bugarinović, Miro Govedarica, Aleksandar Ristić, Željko Bugarinović and Igor Ruskovski ANALYSIS AND APPLICATION OF TERRESTRIAL LASER SCANNING ALGORITHMS FOR DAM MONITORING	151
Mateja Držečnik and Uroš Klanšek PROPOSAL OF DECREE ON CONSTRUCTION SITES IN SLOVENIA	160
Jelena M. Andrić THE POSSIBILITIES OF BLOCKCHAIN TECHNOLOGY AND SMART CONTRACTS IN CONSTRUCTION PROJECTS	167
Nikola Vitomir, Dušan Biočanin and Predrag Petronijević SITE FRONTIER - SOFTWARE FOR PROCESS OPTIMIZATION DURING STEEL STRUCTURE ERECTION WORKS	176
Rok Cajzek, Uroš Klanšek and Mateja Držečnik CONSTRUCTION OF NEW MARIBOR LIBRARY IN ROTOVŽ CENTRE AND CONSERVATION WORKS ON ITS OLDEST COMPLEX "LEDENICE"	187
Suzana Draganić, Mirjana Laban, Mirjana Malešev, Srđan Popov and Marko Marković INTRODUCING A NOVEL DECISION SUPPORT TOOL FOR BUILDING RENOVATION MANAGEMENT	195

Jelena M. Andrić and Aleksandar Pujović A REVIEW OF APPLIED METHODS FOR FLOOD RISK ASSESSMENT	205
Jovana Topalić and Vladimir Mučenski THE MANAGEMENT RISKS IN THE RISK ASSESSMENT MODEL MADE FOR WASTEWATER TREATMENT	216
Zvonko Sigmund, Matej Mihić, Anita Cerić, Ivona Ivić, Sonja Kolarić, Meho Saša Kovačević, Lana Lovrenčić Butković, Mladen Vukomanović and Ivica Završki METHODS OF MEASURING WORKER PRODUCTIVITY FOR ENERGY-EFFICIENT CONSTRUCTION IN THE NORMENG PROJECT	221
Goran Milutinović, Nenad Pecić, Rade Hajdin, Snežana Mašović and Duško Bobera A PRACTICAL METHOD FOR STRUT-AND-TIE MODELLING OF THE BRIDGE PILE CAP	233
Marko Marinković and Christoph Butenweg DAMAGE OF MASONRY INFILLED RC STRUCTURES IN FEBRUARY 2023 EARTHQUAKE SEQUENCE IN TURKEY. DECOUPLED INFILL AS A SOLUTION FOR BETTER BEHAVIOUR	245
Domagoj Tkalčić, Bojan Milovanović, Mergim Gaši, Marija Jelčić Rukavina and Ivana Banjad Pečur COMPOSITE LIGHTWEIGHT PANEL WITH INTEGRATED LOAD-BEARING STRUCTURE	257
Tomaž Pazlar, Martin Hladnik and Boris Azinović EXPERIMENTAL CAMPAIGN FOR DETERMINATION OF MECHANICAL CHARACTERISTICS OF DOWEL LAMINATED TIMBER	265
Branka Mrduljaš, Marin Šepuka and Ana Baričević DEVELOPMENT OF MAGNESIUM PHOSPHATE CEMENT USING LIGHT BURNED MAGNESIUM OXIDE	275
Tiana Milović, Vesna Bulatović, Milan Marinković and Anka Starčev-Čurčin PHYSICOMECHANICAL AND DEFORMATION PROPERTIES OF REPAIR CEMENT MORTARS MODIFIED WITH SLAG	285
Dušan Kocić, Jelena Bijeljić and Nenad Ristić COMPARATIVE ANALYSIS OF CONCRETE TEST RESULTS WITH DIFFERENT AMOUNTS OF FLY ASH ADMIXTURES	293
Laura Sofia Gomez Jaramillo, Marcel Hermans and Marija Nedeljković CONCRETE SURFACE CHARACTERISATION WITH HANDHELD XRF: EFFECT OF WATER-TO-CEMENT RATIO, AGEING AND RELATIVE HUMIDITY	300
Jelena Bijeljić, Nenad Ristić, Dušan Kocić, Dušan Grbić, Zoran Grdić and Gordana Topličić - Čurčić POSSIBILITIES OF GROUND GRANULATED BLAST FURNACE SLAG USAGE IN GEOPOLYMER MIXTURES	313
Bojan Milovanović, Domagoj Tkalčić, Mergim Gaši and Marija Jelčić Rukavina USING MATHEMATICAL MODELS TO PREDICT SORPTION BEHAVIOUR OF PUR	322
Liljana Dimevska Sofronievska, Meri Cvetkovska, Ana Trombeva Gavriloska and Teodora Mihajlovska AEROGEL BASED MATERIALS POTENTIAL IN CIRCULAR ECONOMY, ENERGY EFFICIENCY AND CULTURAL HERITAGE BUILDINGS' RENOVATION	331
Marija Jelčić Rukavina, Davor Skejić, Ivana Banjad Pečur and Martina Mataković THE INFLUENCE OF GYPSUM-FIBER BOARDS ON HEAT TRANSFER THROUGH LSF COMPOSITE PANELS WITH COMBUSTIBLE INSULATION	338
Mergim Gaši, Bojan Milovanović, Domagoj Tkalčić and Marija Jelčić Rukavina THE EFFECT OF THERMAL BRIDGES ON TOTAL HEAT LOSSES OF LSF WALLS	344
Aleksandar Pančić and Dragan Milašinović BUCKLING OF CONCRETE PANELS UNDER BIAXIAL COMPRESSION ACCORDING TO RHEOLOGICAL-DYNAMICAL THEORY	355
Dragan Hristovski TYPES OF SAFETY SCAFFOLDING IN CONSTRUCTION	367
Elena Delova, Aleksandar Zlateski, Angela Poposka, Živko Božhinovski and Veronika Shendova ANALYSIS OF THE STABILITY WITH A TECHNICAL SOLUTION FOR STRENGTHENING OF A FIRST CATEGORY BUILDING IN BITOLA	375
Katarina Didulica, Ana Baričević, Branka Mrduljaš and Alen Čenanović THE USE OF WASTE CARBON FIBRES FOR THE PRODUCTION OF CONDUCTIVE CEMENTITIOUS MATERIALS	384
Željka Beljkaš, Biljana Ivanović, Njegoš Beljkaš and Mladen Gogić OVERVIEW OF A TECHNICAL-TECHNOLOGICAL AND ORGANIZATIONAL STUDY FOR ROAD CONSTRUCTION OF MIDDLE SECTION BUDVA BYPASS	392
Daniel Tomić and Igor Gjorgjiev RC JOINT STRENGTHENING WITH FRP	405
Aleksandar Zhurovski, Aleksandar Zlateski, Elena Delova, Goran Jekić, Roberta Apostolska, Veronika Shendova and Živko Božhinovski SEISMIC UPGRADING OF TELECOMMUNICATION CENTER IN SKOPJE	413

Milena Senjak Pejić, Mirjana Terzić, Dragana Stanojević, Igor Peško, Maja Petrović, Mirna Kapetina and Vladimir Mučenski ESTIMATING CONCRETE QUANTITIES USING ARTIFICIAL INTELLIGENCE-BASED MODELS FOR RECYCLING AND REDUCING CO2 EMISSIONS	425
Zlatko Zafirovski, Ivona Nedevska, Vasko Gacevski, Riste Ristov, Slobodan Ognjenović, Marijana Lazarevska and Saso Kostadinovski AN APPROACH FOR RAILWAY PROJECT MANAGEMENT	436
Snežana Ilić, Igor Džolev and Mirjana Laban OPTIMAL NUMERICAL MODEL OF A NON-STATIONARY HEAT TRANSFER THROUGH A WALL	444
Bojan Milošević, Nenad Kojić, Vladimir Mandić, Milena Čančarević and Luka Lukić ONE IMPLEMENTATION OF ARTIFICIAL INTELLIGENCE SOFTWARE FOR SEGMENTATION AND WALL COMPRESSION STRENGTH PREDICTION	453
Vladimir Vukobratović SEISMIC DEMANDS FOR RIGID ANCILLARY ELEMENTS IN THE SECOND GENERATION OF EUROCODE 8	465
Dragana Stanojević, Vladimir Mučenski, Mirjana Terzić, Milena Senjak Pejić, Igor Peško and Milan Trivunić CONSTRUCTION COST ANALYSIS OF RURAL TOURISM FACILITIES	471
Goran Chapragoski and Golubka Nechevska Cvetanovska FINITE ELEMENT ANALYSIS OF CFRP CONFINED CONCRETE CYLINDERS	480
Marko Stojanović, Ksenija Janković, Dragan Bojović, Anja Terzić and Lana Antić Arandžević INFLUENCE OF RECYCLED RUBBER ON SOME PROPERTIES OF CONCRETE	487
Šime Serdarević, Dalibor Gelo, Ivan Volarić and Dean Čizmar RECONSTRUCTION OF A TYPICAL RESIDENTIAL BUILDING AFTER THE EARTHQUAKE IN PETRINJA	495
Marijana Milić, Goran Jeftenić, Ljubomir Budinski, Danilo Stipić and Slobodan Kolaković MATHEMATICAL MODELLING OF GROUNDWATER FLOW IN POROUS MEDIUM	512
Tatjana Kočetov Mišulić, Branislav Kovačević, Aleksandra Radujković, Ivan Lukić and Slobodan Šupić INTRODUCTION OF POPLAR WOOD IN BUILDING CONSTRUCTION SECTOR: REASONS AND POSSIBILITIES	524
Mirjana Terzić, Jasmina Dražić, Milena Senjak Pejić and Dragana Stanojević AN OVERVIEW OF BUILDING INFORMATION MODELLING AND ARTIFICIAL INTELLIGENCE INTEGRATIONS IN THE CONSTRUCTION INDUSTRY	534
Nikolina Čirić CRITICAL AMOUNTS OF PRECIPITATION FOR ACTIVATING LANDSLIDES IN THE DONJI MILANOVAC – TEKIJA REGION	544
Panta Krstić, Milan Marinković and Dragana Stanojević SKID RESISTANCE AND NOISE EMISSION OF DIFFERENT TYPES OF ASPHALT PAVEMENTS	552
Panta Krstić, Tijana Majkić, Tiana Milović and Milan Marinković UNCONFINED COMPRESSIVE STRENGTH OF DIFFERENT SOIL TYPES STABILIZED WITH CEMENT AND CLINOPTILOLITE MIXTURE: A REVIEW	560
Vladan Pantić, Slobodan Šupić and Ivan Lukić WATER VAPOUR PERMEABILITY OF MASONRY MORTAR BLENDED WITH A HIGH SHARE OF WASTE MATERIALS	568
Dušan Kovačević and Leposava Grubić Nešić CONTEMPORARY TREND IN HIGH EDUCATION: HOW, WHY AND HOW MUCH?	575
Dalibor Gelo, Šime Serdarević, Dean Čizmar and Ivan Volarić THE DESIGN OF THE WATER PUMP STATION	584
Ksenija Janković, Dragan Bojović, Marko Stojanović, Anja Terzić and Srdoljub Stanković FROST RESISTANCE OF HEAVYWEIGHT SELF-COMPACTING CONCRETE	590
Meri Cvetkovska, Camila Cervantes, Adriana Salles, Rand Askar, Ana Trombeva Gavriloska and Luis Braganca IMPLEMENTATION OF CIRCULAR ECONOMY IN THE BUILT ENVIRONMENT	598
Olivera Bukvić, Mirjana Malešev, Suzana Draganić, Marijana Serdar and Vlastimir Radonjanin INFLUENCE OF SUNFLOWER HUSK ASH CONTENT ON THE COMPRESSIVE STRENGTH OF ALKALI-ACTIVATED SLAG MORTARS	606
Slobodan Šupić, Vladan Pantić, Gordana Bročeta, Ivan Lukić and Anđelko Cumbo VALORIZATION OF CORN COB ASH AS AN ENVIRONMENTALLY FRIENDLY SCM IN MASONRY MORTAR	613
Martin Vyšvařil, Tomáš Žižlavský, Martin Krebs and Karel Dvořák REACTIVITY OF NATURAL POZZOLANS IN LIME MORTARS	621
Tanja Nožica, Đorđe Jovanović, Drago Žarković and Andrija Rašeta VERIFICATION OF BUCKLING ANALYSIS OF BEAM FINITE ELEMENT MODEL INCLUDING WARPING IN MATRIX 3D	630

ARCHITECTURE AND URBAN PLANNING

Dragana Konstantinović, Maja Momirov and Nina Čegar RETHINKING THE CONCEPT OF A GENERAL URBAN CENTER IN CONTEMPORARY DESIGN PRACTICE AND ARCHITECTURAL EDUCATION	643
Željko Jakšić and Milan Trivunić THE VALUATION'S ELEMENTS FOR UNEQUAL APARTMENTS STRUCTURE IN THE SAME LOCATION	650
Violeta Stefanović THE INFLUENCE OF THE PHYSICAL ENVIRONMENT OF RESIDENTIAL AREAS ON QUALITY OF LIFE	659
Višnja Žugić and Maja Momirov LOGIC OF FORM VS. FORMALISM: TEACHING DESIGN IN ARCHITECTURE	668
Enis Hasanbegovic, Melisa Alcan, Lejla Zečirović, Julija Aleksić and Danilo Dragović TRANSFORMATION OF ARCHITECTURE AND URBANISM DUE TO CHANGE OF GENDER ROLES IN SOCIETY	680
Aleksandar Zlateski, Veronika Shendova and Elena Delova HARMONIZATION AND IMPLEMENTATION OF SEISMIC VULNERABILITY ASSESSMENT OF THE URBAN HISTORIC CENTER OF SKOPJE	689
Sofija Priljeva THE VALUE CRITERIA OF CITIZENS IN PERCEIVING THE FUNCTION OF PUBLIC SPACES	699
Enis Hasanbegovic, Melisa Alcan, Lejla Zečirović, Branko Slavković and Džemila Beganović NOVI PAZAR CITY CENTER'S DETAILED URBAN PLAN FROM 1968. SEEN AS A STAGE	715
Hartmut Pasternak, Nataša Živaljevic-Luxor and Thomas Krausche NISH STEEL BRIDGES ON NISHAVA	730
Dušan Tomanović, Marta Grbić and Tijana Tomanović 19TH CENTURY FRONT TERRACED RURAL HOUSES AT THE VRMAC PENINSULA-THE BAY OF KOTOR (MONTENEGRO)	737
Ana Trombeva-Gavriloska, Teodora Mihajlovska, Liljana Dimevska Sofronieska and Meri Cvetkovska ADAPTIVE REUSE OF NEGLECTED AREAS IN SKOPJE BY IMPLEMENTING OF THE CIRCULAR ECONOMY	750
Damjana Nedeljković, Tatjana Jurenić and Aleksandra Čabarkapa THE MULTI-CRITERIA DECISION MAKING MODELS: APPROACH DEVELOPMENT THROUGHOUT THE HISTORY	760
Olivera Nikolić, Ana Momčilović Petronijević, Mirko Stanimirović, Marko Joksimović and Vladan Nikolić THE BUILDING HERITAGE OF DEPOPULATED RURAL SETTLEMENTS IN THE MUNICIPALITY OF CRNA TRAVA AS A PARAMETER OF THE REVITALIZATION MODEL	768
Dragan Hristovski PLANNING OF WORKPLACE LIGHTING	784

GEODESY AND GEOINFORMATICS

Nikola Santrač, Pavel Benka and Mehmed Batilović TRANSFORMATION PARAMETERS OF LOCAL FITTING OF DIGITAL ELEVATION MODELS IN THE AREA OF KOVILJSKO-PETROVARADINKI RIT	792
Bogdan Bojović, Žarko Nestorović, Milan Trifković, Miroslav Kuburić and Jelena Tatalović INTEGRATED SYSTEMS OF GEODETIC MEASUREMENTS IN ENGINEERING	804
Dragana Skorup, Goran Marinković, Marko Božić and Miroslav Vujasinović THE POSSIBILITY OF USING INTEGRATED GIS SYSTEMS AND PUBLICLY AVAILABLE REMOTE SENSING DATA FOR THE PURPOSES OF LAND VALUATION IN LAND CONSOLIDATION	811
Gordana Nataroš and Marina Davidović Manojlović REGISTRATION OF PROPERTY RIGHTS ON THE CONSTRUCTION LAND	822
Goran Marinković, Žarko Nestorović, Zoran Ilić and Marko Božić PARALLELISM OF STRAIGHT LINES DETERMINED BY GEODETIC METHODS TESTING	829
Isidora Knežević, Gordana Jakovljevic and Miro Govedarica FOREST CHANGE DETECTION BASED ON SENTINEL 2 IMAGES	837
Igor Ruskovski, Milan Gavrilović and Miro Govedarica PERFORMANCE AND ACCURACY ANALYSIS OF LEICA P20 SCANNER AND IPHONE LIDAR SENSOR IN SCANNING OF CULTURAL HERITAGE OBJECTS	850
Almin Đapo, Damir Medak, Marko Pavasović and Mario Miler GEODESY AND GEOINFORMATION IN THE SERVICE OF REMEDIATION OF DAMAGES FROM NATURAL DISASTERS, EXAMPLES OF ZAGREB AND PETRINJA EARTHQUAKES IN 2020	861

DISASTER RISK MANAGEMENT AND FIRE SAFETY

Milan Trivunić, Željko Jakšić, Dušanka Plazina-Pevač, Igor Peško and Vladimir Mučenski DATA COLLECTION ORGANIZATION FOR THE ASSESMENT OF HIGH-RISE BUILDINGS CONDITION	863
Mirjana Kačarević, Slobodan Šupić and Mirjana Laban FIRE RISK ASSESSMENT OF THE ELEMENTARY SCHOOL "VUK KARADŽIĆ" IN BIJELJINA	870
Jana Opačić, Mirjana Laban and Suzana Draganić CONTEMPORARY METHODS OF SAFE EVACUATION ANALYSIS	881
Dubravka Mandić Ilić and Senka Bajić RISK ASSESSMENT FOR POSITION OF THE CHIEF FIRE OFFICER	892
Mirjana Laban, Suzana Draganić, Marko Marković, Ljiljana Popović, Srđan Popov and Meri Cvetkovska JOINED FOR SUSTAINABILITY – BUILDING CLIMATE RESILIENT COMMUNITIES IN WB AND EU	899

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THE MULTI-CRITERIA DECISION MAKING MODELS IN ARCHITECTURE: APPROACH DEVELOPMENT THROUGHOUT THE HISTORY

Damjana Nedeljković¹, Tatjana Jurenić², Aleksandra Čabarkapa³

Summary:

Multi-criteria models for decision-making are an instrument used in various fields within processes that require a choice between several alternatives, and are based on the comparison of various aspects of potential solutions, among which it is possible to establish a hierarchy. A certain number of such models are also applied in the field of architecture, and they are intended, among other things, to evaluate the potential of buildings for various types of adaptations or to select an adequate intervention in relation to the current state and characteristics of the observed object and its location. The paper represents the historical development of models for decision-making and the influence on the creating of contemporary multi-criteria models, the application of experiences from other fields, grouping according to certain criteria and the shaping of elements of multi-criteria models throughout history.

Key words: multi-criteria decision making models, historical aspect, development, types of models, elements

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1. INTRODUCTION

Depending on the problem to be solved, the number and characteristics of the solutions offered and the differences in the interests of the participants, the decision-making process can be very complex. In those cases, participants use techniques, which can be formal (cost-benefit analysis, multiple criteria decision analysis, decision trees, etc.) and informal (which are not the subject of research in this paper) to help making decisions. All formal decision support techniques are similar in that they contain a set of clearly defined rules on the basis of which the necessary data are selected and evaluated. Multi-criteria models for decision-making represent one of the formal techniques for decision-making support. These models represent mathematical instruments that are used to more successfully solve problem tasks in various fields.[1] The research is primarily directed towards multi-criteria decision-making models applicable in architecture, but many findings are general and applicable to all models of this type.

In the paper there are two parts.

The first part of the paper, the development of the approach itself, which preceded the emergence of multi-criteria models for decision-making, is presented, various approaches to aid in decision-making are explained and the structure with basic elements is shown, which applies to all multi-criteria models, regardless of their purpose, while the second part of the paper presents nine multi-criteria models that have different uses in architecture.

The main goal of the research is to improve understanding of how to use multi-criteria models for decision-making and their more frequent application in decision-making processes in all suitable fields.

2. DEVELOPMENT OF THE MULTI-CRITERIA DECISION-MAKING MODELS

2.1. APPROACH DEVELOPMENT

The beginnings of the formal research of the decision-making process are not known, but within the process itself, two lines of research are recognized: the first relates to analyzing the origin of decisions and the second relates to utility theory and multiple objective mathematical programming.

Within the first line, Edgeworth's (Francis Ysidro Edgeworth) early work on the indifference contours from the 1880s, Ramsey's (Frank Ramsey) and Finetti's (Bruno de Finetti) subjective expected utility model from the 1930s and von Neumann's (John von Neumann) and Morgenstern's (Oscar Morgenstern) utility theorem from the 1940s.

Multiple objective mathematical programming was mostly developed during the 1970s. The basic characteristic of this approach is a certain reconsideration of explicit estimates of values or utility functions and the focus is on finding ways to choose the most suitable solution.

The author of one of the first known models that have the form of the multi-criteria decision making model that we know today is the American statesman Benjamin Franklin. His way of making decisions, which he called "Moral Algebra", was based on the formation of a list with arguments in favor of the issue and against it. Then, on both sides of the list, arguments that had approximately equal importance were removed, until all arguments were removed on one side. The result is a position with which a number of unremoved arguments remain.[2]

2.2. DECISION AIDING APPROACHES

In the decision-making process, there are different approaches to problem solving, which depend on the profile of the participants in solving the problem. In this paper it

will be presented four basic approaches: normative approaches, descriptive approaches, prescriptive approaches and constructive approaches.

Normative derive models of rationality from a priori established norms. Such norms are an integral part of rational behavior and can refer to ethical, religious norms and laws. Deviation from these norms would result in errors in the decision-making process from a rational aspect. Models with a normative approach are universal and can be applied to help solve problems in any field.

Descriptive approaches derive models of rationality from the perspective of the decision makers themselves. These models are general and applicable to different types of decision makers who are making a decision on a similar type of problem.

Prescriptive approaches find models of rationality for a particular client by interpreting his answers to questions related to preferences. The model is based on the discovery of the decision maker's value system. Therefore, these models are not general, but closely adapted to a particular decision maker and the specifics of his problem.

Constructive approaches, similar to the previously described approach, derive models of rationality from the answers the decision maker gives to questions about preferences. Nevertheless, the "discussion" between the decision-maker and the analyst he addressed is not neutral, but is part of the decision-making process, forming a presentation of the problem with indications of a potential solution. In this approach, structuring and formulating the problem is as important as arriving at a solution.

Previously listed approaches can be divided into two groups. The first group consists of normative and descriptive approaches that are universal, use general models of rationality that are formed independently of the decision maker, while the second group consists of prescriptive and constructive approaches that adapt the model of rationality to the specific decision maker and the specific problem.

Normative and descriptive approaches differ in the process of model formation. Normative models are based on abstract economic facts, and descriptive models are based on empirical observation. The difference between prescriptive and constructive models is also, to a large extent, in the process of forming the model. Prescriptive approaches seek to reveal the value system that exists in the decision-maker himself, before considering the decision-making process. On the contrary, within the framework of constructive models, the existing value systems are not considered, but the decision-maker forms the value system during the formation of the model, noting that these two processes are mutually conditioned. [1]

2.3. BASIC ELEMENTS OF THE MULTI-CRITERIA DECISION MAKING MODELS

Although multi-criteria decision-making models differ from each other depending on what they are intended for, the same basic elements are recognized in the structure of each of them. The creation of each multi-criteria model begins with the definition of the problem, then the system of preferences is determined, a set of criteria is formed, and one or more outranking methods with a weighting system are determined. Each of these elements will be explained in Table 1.

Tab. 1 Preview of the basic elements of the multi-criteria decision-making models

Basic elements of the multi-criteria decision making models	Defining a problem	
	Formulating a problem	Problem structuring
	<ul style="list-style-type: none"> - to translate the decision maker's problem in decision support language into a "formal" problem so that decision support techniques and methods can be used in solving; - the formulation of the problem directs the further steps of decision-making.[1] 	<ul style="list-style-type: none"> - to find a suitable decision and/or evaluation model, based on the previously formulated problem; - some of the well-known methodologies for structuring problems are: cognitive mapping, strategic choice, soft systems methodology, valued focused thinking, integrating approaches. [1]
	Preference detection system	
	<ul style="list-style-type: none"> - recognition of the decision-maker's preferences over the set of alternatives; - detection of preference relation among alternatives previously evaluated according to certain dimensions; - some of the preference detection systems with many variations: pointwise evaluations on an ordinal scale, pointwise evaluations on an interval scale, pointwise evaluations on a ratio scale, interval evaluations on an ordinal scale, etc.[1] 	
	Criteria	
	<ul style="list-style-type: none"> - different types of criteria and indicators according to which alternatives are evaluated;[1] - three groups of criteria are recognised in multi-criteria decision-making models used in a field of architecture: general criteria and indicators, specific criteria and indicators determined by the type of adaptation and specific criteria and indicators determined by the specific context.[3] 	
	Outranking methods	
	<ul style="list-style-type: none"> - aggregation methods used for creating a global preference relation which is based on pairwise comparisons of the alternatives; - some of the outranking methods used in multi-criteria decision-making models are: ELECTRE, PROMETHEE, MAUT, TACTIC, etc.[1] 	
	Weighting system	
	<ul style="list-style-type: none"> - determination of the relative importance of the different criteria using weights – non-negative numbers, which values are independent from measurements units of the criteria.[3] 	

3. THE MULTI-CRITERIA DECISION MAKING MODELS IN ARCHITECTURE

After basic steps in decision making process and structural elements of every multi-criteria decision making model, in this part of paper a brief review of nine multi-criteria decision making models used in architecture is presented.

3.1. THE CONVERSION METER MODEL

The *Conversion meter* model is intended to assess the potential for conversion of commercial buildings into permanent and temporary housing. The first version of the

model was created at the end of the twentieth century in the Netherlands, when a large number of business buildings were out of use. The evaluation of the potential is done in several steps, through several lists of criteria, and each positive answer is worth one point. Value ranges are determined on a numerical scale that are linked to a certain level of potential of a business object for conversion. The specificity of this model is the use of "veto" criteria, which, if not met, stop further evaluation.[4]

3.2. THE TOBUS MODEL

The *TOBUS* (*Tool for selecting office building upgrading solutions*) model is the result of joint research by experts from several European countries (Denmark, France, Greece, Switzerland and the Netherlands) and was developed within the European research program JOULE III. It is intended to assess the current state of the business facility, on the basis of which a set of interventions for improvement is proposed. Essentially, the model has the ability to propose a large number of different scenarios and an analysis of the financial and energy aspects of the realization of a potential adaptation. In order to make it easier to use, the software of the same name was developed, which, initially, uses data related to the territory of Switzerland, but the structure of the software is designed so that it is possible to enter data relevant to other countries.[5]

3.3. THE XENIOS MODEL

The *XENIOS* model or methodology is a multi-criteria model intended to help in the decision-making process related to different scale of adaptations of hotels. The model offers a technical and economic assessment of potential interventions, taking into account the specifics of this group of buildings, while relying on experiences in the field of different types of adaptations of residential and commercial buildings. For potential users of the model, the software which is programmed to estimate the total costs of various scenarios - potential types of adaptation and to recommend related to improving the energy properties of buildings, installation of renewable energy sources can be obtained, was designed. Through special modules for assessing the sustainability of buildings and their impact on the environment, techniques are proposed for the rational use of energy.[6]

3.4. THE MEDIC MODEL

The *MEDIC* model is designed so that it can be used with the *EPIQR* model, which will be explained below. The model divides each object into fifty elements, and, through the use of four codes (which are also used in the *EPIQR* model) an assessment and description of the state of all elements of the object is performed. Based on the experience gathered by analyzing a large number of other objects and data related to a specific object, using the *MEDIC* model, the remaining "expected life" of the object can be calculated. The expected remaining duration of building elements is not only one of the criteria when choosing the type of adaptation, but also when evaluating the energy and environmental characteristics of the building. The above estimates are important when planning investments, since they allow the owner and/or investor to decide what is the most reasonable moment to start the adaptation of the building.[7]

3.5. THE EPIQR MODEL

The *EPIQR* (*Energy performance indoor environmental quality retrofit*) model is based on a detailed description of the object for which some type of adaptation is being considered. As described in the part with the *MEDIC* model, in the model, the building is divided into fifty elements such as facades, installation systems, etc. Each of the elements is described by one of the four degrees of degradation (represented through the codes discussed in the part about the *MEDIC* model). More than eight hundred potential

descriptors are used to define the state of the object. The assessment of the potential for some kind of adaptation is considered through criteria that are grouped into four aspects: the quality of the interior space, the required amount of energy, potential costs and measures of subsequent equipment. The analysis of these aspects can help when choosing the optimal way to adapt the building.[8]

3.6. THE ARP MODEL

The assessment of the potential for the conversion of commercial to residential buildings using the *ARP (Adaptive reuse potential)* model is based on the consideration of the (temporal) moment in which the building is located in relation to its estimated useful life. In the model, first of all, the physical life of the object is evaluated, that is, the possibility of the object's duration as a physical structure, based on a list of criteria. The useful life, that is, the period in which the object is expected to be used for the purpose for which it was built, represents the physical life reduced by various factors. In this model, result is displayed graphically, through a diagram, and through a numerical scale within which the ranges of values associated with the specific potential of the business object for repurposing are determined.[9]

3.7. THE ADAPTSTAR

The *AdaptSTAR* model is a tool designed to assess the future adaptive potential of buildings under construction. The future possibility of the building adaptive reuse is considered as one of the key criteria during the process of building design. In order to check the adaptive reuse potential of the building, the *ARP* model will be used. The *AdaptSTAR* model is designed as a weighted checklist for different design strategies aimed at high-potential of buildings for future conversion. The list of criteria for the building design was compiled based on the assessment of professionals from the architectural profession. The model is based on the analysis of case studies, interviews with experts and surveys conducted among participants in the processes of adaptive reuse in practice.[10]

3.8. THE ICONCUR MODEL

The *iconCUR* model considers the potential of a business object for various types of adaptations, based on a set of criteria. The evaluation takes place through a diagram, which is designed as a spatial grid, the sides of which are different types of adaptations, and the object is positioned according to certain coordinates. The distance of the object from the sides of the spatial grid is measured. By using this model, it is possible to see the potential of several objects simultaneously or of one object over time. The specificity of this model is the establishment of a hierarchy among the criteria, which has an impact on the final result.[11]

3.9. THE PAAM MODEL

The *PAAM (Preliminary assessment adaptation model)* model is intended to assess the potential of business facilities for upgrading. This paper discusses the large number of criteria that are important for all types of adaptations and the way of establishing a hierarchy among the criteria. The selection of the criteria of this model, as well as the method of valorization, is based on statistical data collected by analyzing a large number of objects on which this type of adaptation was carried out, where the influence (in percentage) of each criterion on the final outcome is estimated, and the percentage share is determined by the mathematical method *PCA (Principle Component Analysis)*. Criteria that affect the object's potential for this type of adaptation to the same extent are ignored in all analyzed cases.[12]

4. DISCUSSION AND CONCLUSION

Multi-criteria models represent one of the formal forms of assistance in the process of solving problems in various fields. Through the analysis of the development of ideas on which multi-criteria decision making models are based, it can be concluded that the need for rationalization and formatting of thought processes and opposing views in the decision-making process existed long before the emergence of today's forms of models in this area.

The first part of the paper is generally applicable for multi-criteria decision models intended for use in any field and presents the basic ways of thinking on which the logic of multi-criteria decision making models is based and the basic elements recognized in the structure of each of those models. Each of the elements has a number of variations, the combination of which provides the possibility of forming a multi-criteria decision making model that corresponds to the specifics of individual cases.

In the second part of the paper, an overview of multi-criteria decision making models used in different parts of the architectural field is presented. Some of these models are intended for choosing the best solution among the offered alternatives, others are focused on assessing the degree of suitability of one solution in a specific case. It was noticed that some of the analysed models were created together, within the same larger project and that they complement each other. This fact indicates the development of the idea of applying multi-criteria decision making models in architecture, and it is expected that the application of these models in the early stages of decision-making during the design process will greatly contribute to the quality of the final product - built environment.

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REFERENCES

- [1] Bouyssou, D., Marchant, T., Pirlot, M., Tsoukias, A. & Vincke, P. (2006). Evaluation and decision models with multiple criteria. New York, Springer Science+Business Media, Inc.
- [2] Koksalan, M., Wallenius, J. & Zionts, S. (2005). An Early History of Multiple Criteria Decision Making. In: Greco, S. (Ed.). *Multiple Criteria Decision Analysis: State of the Art Surveys*. Springer: London: New York. 3- 17.
- [3] Nedeljkovic, D., Jurenic, T. & Djokic, L. (2023). Comparative analysis of multi-criteria models for decision-making in the process of building adaptation. *Heliyon* 9 (6), doi: 10.1016/j.heliyon.2023.e16620.
- [4] Geraedts, R. P., Van der Voordt, T. & Remoy, H. (2018). Conversion Potential Assessment Tool. In book. S. Wilkinson & H. Remoy (Eds.), *Building Resilience in Urban Settlements through sustainable change in use* (121-151). Wiley Blackwell.
- [5] Flourentzou, F., Genre, J. & Roulet, C-A. (2002). TOBUS software – an interactive decision aid tool for building retrofit studies. *Energy and Building* 34: 193-202.
- [6] Dascalaki, E. & Balaras, C. (2004). XENIOS – A methodology for assessing refurbishment scenarios and the potential of application of RES and RUE in hotels. *Energy and Buildings* 36 (11), 1091 – 1105.
- [7] Flourentzou, F., Brandt, E. & Wetzel, C. (2000). MEDIC – A method for predicting residual service life and refurbishment investment budgets. *Energy and Buildings* 31 (2), 167 – 170.
- [8] Jaggs, M. & Palmer, J. (2000). Energy performance indoor environmental quality retrofit – a European diagnosis and decision making method for building refurbishment. *Energy and Buildings* 31 (2), 97 – 101.
- [9] Langston, C. (2014). Identifying Adaptive Reuse Potential. In. S.J. Wilkinson, H. Remoy and C. Langston. *Sustainable Building Adaptation: Innovation in Decision-Making*. Wiley Blackwell.
- [10] Conejos, Sh., Langston, C. & Smith, J. (2012). AdaptSTAR model: A climate-friendly strategy to promote built environment sustainability. *Habitat International* 37, 95 – 103.

- [11] Langston, C. (2014). Modelling Building Performance Using iconCUR. In. S.J. Wilkinson, H. Remoy and C. Langston. Sustainable Building Adaptation: Innovation in Decision-Making. Wiley Blackwell.
- [12] Wilkinson, S.J. (2014). The preliminary assessment of adaptation potential in existing office buildings. *International Journal of Strategic Property Management* 18 (1), 77-87.