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Preface

This volume, Proceedings of The 15th International Symposium on Operations Research, called SOR'19, contains papers presented at SOR'19 (http://sor19.fov.uni-mb.si/) that was organized by Slovenian Society INFORMATIKA (SDI), Section for Operations Research (SOR), University of Maribor, Faculty of Organizational Sciences, Kranj, Slovenia, and University of Ljubljana, Faculty of Mechanical Engineering, Ljubljana, Slovenia, held in Bled, Slovenia, from September 25 to September 27, 2019. The volume contains blindly reviewed papers or abstracts of talks presented at the symposium.

The opening address at SOR'19 was given by Prof. Dr. Lidija Zadnik Stirn, President of the Slovenian Section of Operations Research, Mr. Niko Schlamberger, President of the Slovenian Society Informatika, Prof. Dr. Iztok Podbregar, Dean of the Faculty of Organizational Sciences, University of Maribor, Prof. Dr. Mitjan Kalin, Dean of the Faculty of Mechanical Engineering, University of Ljubljana, Prof. Dr. Immanuel Bomze, President of The Association of European Operational Research Societies (EURO),), Prof. Dr. Zrinka Lukać, President of Croatian Operational Research Society (CRORS), and presidents/representatives of some others Operations Research Societies from abroad.

SOR'19 is the scientific event in the area of operations research, another one in the traditional series of the biannual international OR conferences, organized in Slovenia by SDI-SOR. It is a continuity of fourteen previous symposia. The main objective of SOR'19 is to advance knowledge, interest and education in OR in Slovenia, in Europe and worldwide in order to build the intellectual and social capital that are essential in maintaining the identity of OR, especially at a time when interdisciplinary collaboration is proclaimed as significantly important in resolving problems facing the current challenging times. Further, by joining IFORS and EURO, the SDI-SOR agreed to work together with diverse disciplines, i.e. to balance the depth of theoretical knowledge in OR and the understanding of theory, methods and problems in other areas within and beyond OR. We believe that SOR'19 creates the advantage of these objectives, contributes to the quality and reputation of OR by presenting and exchanging new developments, opinions, experiences in the OR theory and practice.

SOR'19 was highlighted by five distinguished keynote speakers. The first part of the Proceedings SOR'19 comprises invited abstracts and papers, presented by five outstanding scientists: Acad. Prof. Dr. Ivan Bratko, Faculty of Computer and Information Science, University of Ljubljana, Ljubljana, Slovenia, Prof. Dr. Mirjana Čižmešija, University of Zagreb, Faculty of Economics and Business, Zagreb, Croatia, Assoc. Prof. Dr. Tibor Illés, Budapest University of Technology and Economics, Institute of Mathematics, Budapest, Hungary, Prof. Dr. Joanna Józefowska, Poznan University of Technology, Poznan, Poland (the EURO plenary), and Prof. Dr. Matej Praprotnik, Laboratory for Molecular Modeling, National Institute of Chemistry, Ljubljana, Slovenia.

Proceedings includes 106 papers or abstracts written by 203 authors. Most of the authors of the contributed papers came from Slovenia (79), then from Croatia (43), Czech Republic (13), Hungary (12), Slovak Republic (12), Poland (9), Austria (7), Spain (5), France (4), Netherlands (3), Portugal (3), Italy (2), Norway (2), Romania (2), Thailand (2), Germany (1), Indonesia (1), Ireland (1), Serbia (1), and United Kingdom (1). The papers published in the Proceedings are divided into Plenary Lectures (5 abstracts), seven special sessions: Application of Operation Research in Agriculture and Agribusiness Management (5 papers), Formal and Behavioral Issues in MCDM (6 papers and 1 abstract), Graph Theory and

Algorithms (11 papers and 1 abstract), High-Performance Computing and Big Data (4 papers), Optimization in Human Environments (7 papers), System Modelling & Soft Operational Research (5 papers), Towards Industry 4.0 (5 papers), and eight sessions: Econometric Models and Statistics (10 papers), Environment and Social Issues (5 papers and 1 abstract), Finance and Investments (11 papers), Location and Transport, Graphs and their Applications (4 papers), Mathematical Programming and Optimization (7 papers and 2 abstracts), Multi-Criteria Decision-Making (6 papers), Human Resources (4 papers), and Production and Management (6 papers).

The Proceedings of the previous fourteen International Symposia on Operations Research organized by the Slovenian Section of Operations Research, that are listed at https://www.drustvo-informatika.si/sekcije/sor/sor-publikacijepublications/, are indexed in the following secondary and tertiary publications: Current Mathematical Publications, Mathematical Review, Zentralblatt fuer Mathematik/Mathematics Abstracts, MATH on STN International and CompactMath, INSPEC. The Proceedings SOR'19 are expected to be covered by the same bibliographic databases.

The success of the scientific events at SOR'19 and the present proceedings should be seen as a result of joint effort. On behalf of the organizers we would like to express our sincere thanks to all who have supported us in preparing the event. We would not have succeeded in attracting so many distinguished speakers from all over the world without the engagement and the advice of active members of the Slovenian Section of Operations Research. Many thanks to them. Further, we would like to express our deepest gratitude to prominent keynote speakers, to the members of the Program and Organizing Committees, to the referees who raised the quality of the SOR'19 by their useful suggestions, section's chairs, and to all the numerous people - far too many to be listed here individually - who helped in carrying out The 15th International Symposium on Operations Research SOR'19 and in putting together these Proceedings. Last but not least, we appreciate the authors' efforts in preparing and presenting the papers, which made The 15th Symposium on Operations Research SOR'19 successful.

We would like to express a special gratitude to The Partnership for Advanced Computing in Europe (PRACE) for a financial support and to The Association of European Operational Research Societies (EURO) for financing the EURO plenary speaker.

Bled, September 25, 2019

Lidija Zadnik Stirn
Mirjana Kljajić Borštnar
Janez Žerovnik
Samo Drobne
Janez Povh
(Editors)

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A TABU SEARCH METHOD FOR OPTIMIZING HETEROGENEOUS STRUCTURAL FRAMES

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Abstract: Structural design is responsible for the design and development of structural plans. It consists of multiple steps that have to be performed sequentially. As the output of a step acts as an input for the next one, using optimization tools to aid the design process can help in achieving a better overall quality or a particular design. In this paper, we present a heuristic method that can provide useful suggestions in a short time for the structural design of a building based on preliminary plans. We also introduce a mathematical model that can be used as quality control of the results.

Keywords: structural frames, structural design, tabu search, mathematical model

1 INTRODUCTION

The design and construction of a building is a cost intensive process regarding both operational and capital costs and environmental impacts. The structural design process consists of several stages that have to be performed sequentially: planning, design and detailing. Even separately, these are all complex problems, thus efficient optimization tools can help civil engineers with their decision-making process in order to create cost efficient and sustainable building designs. The *planning* phase is responsible for the development of the initial layout of the structure, positioning and orienting all the required element types within the frame itself. The result of this step is a preliminary design of the building, which contains the positions of all elements, but usually does not specify their important characteristics. The field dealing with this phase is called layout/topology optimization. One of the first introductions of the problem was by Dorne et al. [7] in 1964, and soon more exact approaches followed for different types of structural topologies (see Bendsøe and Kikuchi [3] and Kirsch [9] as some examples). Several different aspects of the problem have been considered over the years. Different types of solution methods have been proposed, like metaheuristics (such as the ant colony optimization of Camp [4]), genetic algorithm (e.g. Deb [6]), or an optimization framework that considers instabilities (Changizi and Jalalpour [5]). For a thorough review of this field, see Rozvany [12].

The outcome of the planning phase is a preliminary design, that is still missing many important structural properties of its elements (e.g exact shape/size, material used). The *design* phase uses this plan as an input, and creates a structural plan that can be passed on the *detailing* phase for the preparation of the construction schedule. Because of this, the goal of the design phase is to prepare a plan that optimizes all arising costs (be it capital, operational or environmental). Similar solution approaches exist for this phase as for *planning*, and the two are often considered together. Again, different genetic algorithms were proposed (for an example, see Baumann and Kost [2] or Fedelinski and Gorski [8]), and metaheuristics are also used (the simulated annealing approach of Lamberti and Pappalettere [10]). For detailed reviews of both the design phase and the combination of planning and design, refer to Lamberti and Pappalettere [11] or Azad and Hasançebi [1].

In this paper, we propose a Tabu search heuristic that can provide quick suggestions for a structure design based on preliminary plans, specifying the material and cross section of the elements in the structure to achieve a low-cost solution. As the method provides solutions in a short time, the results of this algorithm can be used by civil engineers to help with their decision-making processes during the structural design process. A mathematical model is also developed for the same problem so that we can monitor the quality of the heuristic.

First, we introduce the problem itself, and formalize it as a mathematical model. We then present the Tabu search heuristic for its solution, and present preliminary test results on small input instances.

2 PROBLEM DEFINITION

A structural frame can be regarded as the skeleton of a modern building. It consists of separate levels, and each of these can typically contain three different element types: slabs, columns and beams.

Slabs are the plate elements of the structure, which are usually used as the base, roof or ceiling. Beams are horizontal elements that support the slabs, while columns are vertical elements that support the beams and other columns above them. A simplified representation of a structural frame can be seen in Figure 1.

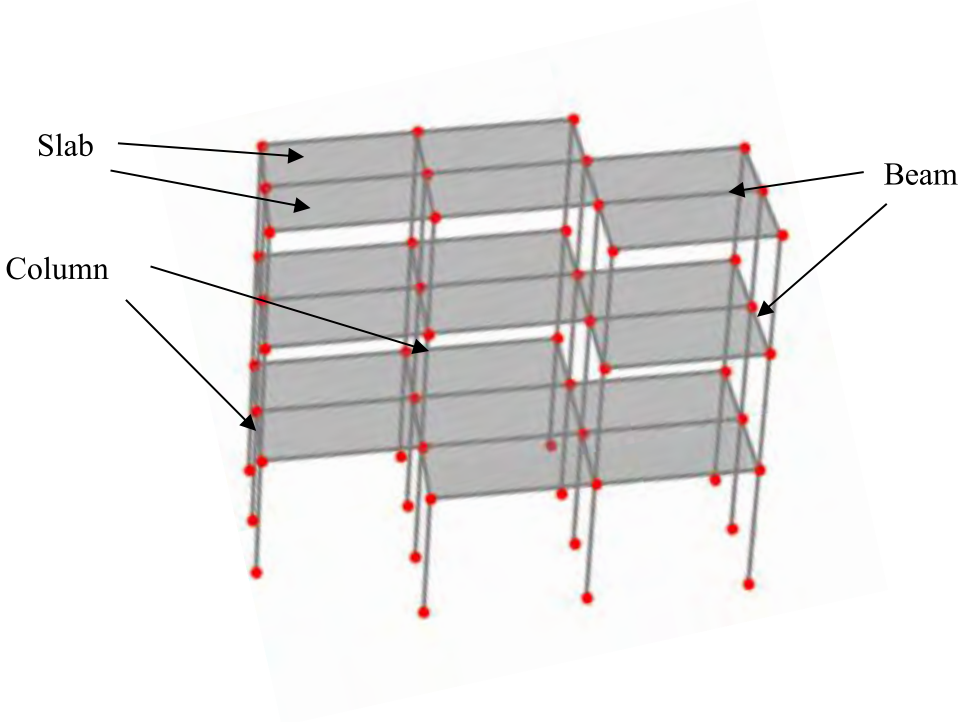

Figure 1: An abstract example of a structural frame

Different materials can be assigned to different elements. However, every element of this frame is affected by certain structural forces, and their cross-section has to be chosen accordingly when the desired material for the element is selected. Another important requirement is that certain elements have to be identical, meaning that they both have to share the same material and have the same cross-section. Such elements will be referred to as '*belonging to the same group*'.

Given all required information about the elements of the structure, and a preliminary conceptual design, we would like to use them to create a design plan that minimizes all arising costs.

In the next section, first we will formally define the above problem, and introduce a mathematical model based on the presented constraints.

2.2 Mathematical model

Let E be the set of elements in our frame and let set G denote the different groups that these elements can belong to. For each $e \in E$, let $g(e) \in G$ be the group of that element. Let M be the set of the available building materials.

The mathematical model of the problem can be formalized the following way:

$$minimize \sum_{e \in E} \sum_{j=1}^{|M|} c_{ej}\, x_{ej}$$

$s.t.$

$$\sum_{j=1}^{|M|} x_{ej} = 1, \forall e \in E \quad (1)$$

$$x_{im} - x_{jm} = 0, \forall i \in E, j \in g(i), 1 \le m \le |M| \quad (2)$$

$$y_{im} = max\{s_{jm} x_{jm} \mid j \in g(i), 1 \le m \le |M|\}, \forall i \in E \quad (3)$$

$$x_{im} \in \{0,1\}, \forall i \in E, 1 \le m \le |M| \quad (4)$$

$$y_i > 0, \forall i \in E \quad (5)$$

The binary variable x_{em} represents the decision of using material m for element e. Variable y_e gives the cross-section of element e in the final plan. Constraint (1) specifies that any given element will have exactly one material. Constraint (2) ensures that elements belonging to the same group will have the same material. Constraint (3) selects the proper cross-section of every element, making sure that elements belonging to the same group should have the same cross-section. Constraints (4) and (5) are the binary and nonnegativity constraints for the two variables respectively. The objective of the model is to minimize the arising costs of the elements in the structure. The cost largely depends on the type of material chosen for the element (the value of x_{em}), an also its cross section. The cross section is included in the objective through the cost coefficients, as they are a factor of the cross section: $c_{em} = \alpha_m y_e$. This cost coefficient includes both the capital and operational costs of the building, as well as its environmental impact.

The above model itself is non-linear because of constraint (3) and the objective. However, since they include the binary variables x_{em}, they both can be linearized easily with the introduction of extra variables.

2.3 A Tabu search heuristic

We developed a Tabu search algorithm for the solution of the problem. This heuristic was chosen for the solution of the problem, as it is able to produce multiple good quality solutions with a short running time. Having multiple solutions can help with the decision-making processes of engineers, as they are provided multiple options to evaluate and use to carry out modifications to the preliminary design.

The pseudo code of the method can be seen in Algorithm 1. The heuristic uses a preliminary design as its initial solution. A single neighborhood transformation is considered: assigning a new material to a group of elements, while the others are left unchanged. The cross section of these elements is also adjusted in accordance with the new material. The material change that results in a structure with the lowest cost is chosen as the best neighbor. The algorithm stores two different solutions. A local solution (s) is used to track the progress of the search, and it changes to the neighbor with the best cost in every iteration, while a best solution (o) is also saved. The *(g,m)* pair is added to the Tabu list, where *g* is the group of elements that was changed in this step, and *m* is the old material that these elements had.

The algorithm iterates until a terminating condition is reached (e,g. a fixed number of steps without any improvement to the best solution, or set iteration limit), and the solution stored in *o* is returned as the final result.

```
s = preliminary solution
o = s
TL = ∅
while no terminating condition reached
        manage TL
        for all groups g
                for all materials m
                        if (g, m) ∈ TL
                                continue
                        p = change all elements in g to material m
                        if cost(p) < cost(s)
                                candidate = p
                                cl = (g, old material of g)
        s = candidate
        TL = TL ∪ cl
        if cost(s) < cost(o)
                o = s
return s
```

Algorithm 1: A Tabu search heuristic

In the case of our problem, the heuristic terminated if the value of the best solution *o* has not improved after a given number of iterations. As the size of the neighbourhood is defined by the number of groups and materials, we chose this iteration number to be the function (more specifically, the product) of the number of groups and materials.

3 PRELIMINARY RESULTS

We tested the Tabu search heuristic on three different instance sets. Table 1 presents the important characteristics (number of beams, columns and slabs) of these.

Table 1: Properties of the test instances

	beams	*columns*	*slabs*	*running time (s)*		
				sc1	*sc2*	*sc3*
Instance 1	89	58	27	23	21	2
Instance 2	72	48	21	6	6	1
Instance 3	72	48	21	8	7	2

Instance 2 and 3 might contain the exact same number of elements, but the layout of these structures is different.

Structures of these sizes would more or less correspond to smaller multi-storey family houses, which might qualify as real-world input, but larger buildings would be more challenging to optimize.

Table 1 also contains the solution times of the mathematical model using Gurobi. These values are presented in three columns (sc1, sc2 and sc3) for every instance, each column representing a different test scenarios:

- *Scenario 1*: elements of the same type belong to the same group.
- *Scenario 2*: elements of the same type on the same floor belong to the same group.
- *Scenario 3*: each element is a single group of its own, and is optimized separately. While this scenario is not realistic, it shows the performance of the algorithm in an extremely large search space.

A preliminary list of cross-sectional data was compiled for each element-material pair based on the different forces affecting the given element. Using this list, the required cross section of an element can easily be decided for any material type. This list was used by both the heuristic and the mathematical model.

We performed 20 test runs for each scenario. Ten of these were using the above list cross-sectional data, while random cross-section values were generated for the other ten. The results of the above scenarios can be seen in Table 2.

Table 2: Average results of the instances

	Scenario 1		*Scenario 2*		*Scenario 3*	
	running time (s)	*gap (%)*	*running time (s)*	*gap (%)*	*running time (s)*	*gap (%)*
Instance 1	0.95	0.00	8.98	0.01	159.54	0.44
Instance 2	1.27	0.00	6.84	0.04	315.60	0.83
Instance 3	1.25	0.00	7.86	0.00	122.90	0.60

Two columns belong to each scenario in the table: the first gives the running time in seconds, while the other presents the gap from the cost of the optimal solution given by the mathematical model. As it can be seen from the results, the algorithm performed well for the first two scenarios with regards to both running time and costs. However, solving the instances of scenario 3 takes a long time, and result in poor quality solutions. It is interesting to note, that because Scenario 3 considered every element as its own group, their cross-sections have been fixed by constraint (3) of the mathematical model. This resulted in the short solution time of the model, while the Tabu search heuristic performed exceptionally poor due to the significantly increased search space.

4 CONCLUSIONS AND FUTURE WORK

In this paper, we presented an optimization problem concerning heterogeneous structural frames. Using a preliminary design as an input, we developed a heuristic that is able to provide good quality solutions with a short running time. This is important, as such a method can help with decision-making process of civil engineers when designing structural plans, as they can consider the outcomes of several scenarios by running such a fast algorithm multiple times.
To measure the quality of this heuristic, we also developed a mathematical model for the problem, that can provide the optimal solutions for the given instances.

While the performance of the heuristic algorithm was satisfactory for smaller instances, it performed poorly for larger instance sets. The neighborhood selection of the algorithm should be modified both to speed up solution process and to find better quality solutions. Another aspect of the problem that should be considered is the multi-objective nature of its cost function. While presently we consider all costs as a linear combination of the different factors, environmental impacts and capital costs should actually be optimized as separate objectives affecting each other.

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Appendix

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