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Planning the reconstruction of a historical building by using a fuzzy stochastic network

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ABSTRACT

The planning of construction projects that feature the reconstruction of historical buildings is a difficult task due to limited knowledge of their structure in terms of architecture and construction, as well as their historical substance. Thus, the planning phase of such a project needs to include various different scenarios for carrying it out, while the occurrence of these scenarios will be random. The uncertainty related to the estimation of the various parameters regarding the particular types of reconstruction work, as well as the probability of their necessity, their duration and cost is also a problem. In an attempt to address these problems, the authors of the paper have suggested a method of planning construction projects involving the reconstruction of historical buildings, which features the use of stochastic networks to model the undetermined structure of such projects; elements of fuzzy logic in the form of interval sets are used to model the uncertainty in estimating the parameters of reconstruction works. The authors have also pointed out the advantage of using this approach over the use of type-1 fuzzy logic, which is currently widely used. In order to improve and shorten the calculation process, a digital tool has been developed for the method in question, which can be put into practical use by property developers and other decision-makers when dealing with problems tied to the planning of the processes of the reconstruction of buildings, especially those of a historical nature. The method presented in the paper and its digital implementation has been used in the modeling and analysis of the construction project featuring the reconstruction of a historical retaining wall at the Wawel Royal Castle in Krakow, which serves as a typical example of a construction project with an undetermined structure. The results that were obtained were compared with the actual results of the project in question, confirming the usefulness of the method.

1. Introduction

1.1. Outline of the problem

The reconstruction of historical buildings is a peculiar and difficult process to carry out. The distinct nature of the process of revalorization stems from the following:

- The duration of reconstruction work, which is hard to assess, due to the limited knowledge of the structure of a given historical building.
- The difficulties associated with assessing the duration and cost of construction and conservation work due to the atypical conditions of performing it, as well as the reconstruction technologies that are used (E. Radziszewska-Zielina and G. Śladowski [1]).

The cause of the difficulty in assessing the duration of construction work is the fact that it is impossible to perform appropriate evaluative tests without affecting a structure's historical substance. A possible alternative to such invasive methods of analysis are non-destructive analysis methods used in evaluating historical buildings. For example K. Martini [2] featured an analysis of the relationship between the type of damage seen in the ancient structures of Pompeii and data on the natural disasters that contributed to the destruction of the town in the past, which in turn made it easier to perform a structural and archaeological verification of the buildings that were analyzed; P. Szymczyk and M. Szymczyk [3] provide a further development of the GPR (Ground Penetrating Radar) technique which entails emitting electromagnetic waves through a historical building and recording reflected waves with the use of specialist software, making it possible to obtain an outline of its structure; B. Riveiro et al. [4] recommend the use of a combination of photogrammetry and GPR to evaluate the technical condition of the masonry structure of an arch bridge; L. Truong-Hong and D.F. Laefer [5] provide an analysis of the response of masonry structures to subsidence with the use of laser scanning. However, the above-mentioned methodologies - the main advantage of which is the use of non-invasive

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methods of analysis - require specialist equipment and qualified researchers, which often generates significant costs that a property developer often cannot afford in the initial phase of planning the reconstruction of a historical building. The fact that the historical substance of a building cannot be fully assessed during the initial phase of planning a reconstruction, forces property developers to acknowledge the multi-variant nature of reconstruction works in response to various situations that may arise from inflicting damage to the structure of a historical building during its reconstruction.

The aforementioned issues make the planning of such projects a very complicated and difficult task, as they require an analysis of many variant methods of carrying them out - in terms of the possibility and probability of their occurrence, as well as in relation to their duration and cost. As a result, these projects are often poorly planned by property developers and often generate unforeseen problems stemming from underestimating their costs and completion deadlines (G. Śladowski and E. Radziszewska-Zielina [6]). In light of the above, there is a need for a tool that - while taking into account the distinct nature of the reconstruction process of a historical building - can allow property developers to properly plan this process in the initial phase of decision-making.

1.2. Review of currently used tools

One of the tools typically used in the planning and control of construction projects are so-called relationship networks. These networks are based on graphs and are a graphical representation of the plan of a project with a specific structure of technological and organizational relationships. Regardless of the type of these networks, we can identify their common elements, such as activities, events and relationships between each activity, as well as their parameters (duration, costs, etc.) that are distinct for a project that is being modeled with their use.

Literature on the subject of network planning provides examples of numerous planning methods, of which the most widely known are CPM (Critical Path Method) and its probabilistic version—PERT (Program Evaluation and Review Technique). Both methods, which are still being developed by F.A. Lootsma [7], S. Chanas and P. Zieliński [8], F.T. Lin and J.S. Yao [9], C.T. Chen and S.F. Hung [10], as well as M. Hajdu [11], are based on a graph with a determined logical structure of connections, and are successfully being used in the planning and control of construction projects.

Experience, however, shows that using traditional methods that feature determined logical structures to model distinct types of construction projects - such as the reconstruction of historical buildings - constitutes a planning error.

The determined logical structure of such networks makes it possible to only model a single scenario for carrying out a planned project by assuming the completion of all of its associated tasks. However, projects that feature the reconstruction of historical buildings need to include alternative scenarios for carrying them out. This means that not all of the tasks will be completed in a real-world scenario.

The concept of the use of network planning to model projects with an undetermined structure was first proposed by H. Eisner [12], who introduced a generalization of traditional networks through the introduction of the GAN (Generalized Activity Network) approach, with a topology of nodes enabling the generation of variant relationships within the structure of a network. S.E. Elmaghraby [13,14] introduced the algebra which enabled the analysis of such networks, provided that their parameters were deterministic. Afterwards, A. Pritsker and B. Alan [15] introduced the GERT (Graphical Evaluation and Review Technique) method, further developed by G.E. Whitehouse [16], which, along with its simulation version —GERTS (Graphical Evaluation and Review Technique Simulation) —became a basic method for analyzing stochastic networks, the parameters of which are random variables with a given probability density.

The literature on the subject of network planning includes examples of using the classic GERT method in the planning of construction projects: A. Kosecki [17] provided examples of using stochastic models in the planning of the restoration of historical buildings; J. Kamburowski and A. Nowak [18] modeled and analyzed the process of building a reinforced-concrete monolithic wall; A. Hougui [19] features an analysis of the construction of a hydroelectric power plant; F. Peña-Mora and M. Li [20] illustrate the use of the GERT method for the dynamic planning and control of the design and construction process of buildings; A. Więckowski [21] developed a general network model of the process of designing and constructing buildings which, apart from including design variants that could be implemented in a random manner, also featured variants that incorporated decision-making; A. Woźniak [22] features the application of the GERT method to plan the construction of a wastewater treatment plant; X. Gao et al. [23] illustrated its usage in the development of risk management plans during preparatory stages of large construction projects; and B. Wang et al. [24] used it for quality management in the construction of a concrete dam.

Nevertheless, as we can see from the examples provided above, the deterministic or probabilistic method of modeling the basic parameter - the duration of the performance of a planned project - requires empirical data in its formulation.

In the case of projects featuring the reconstruction of historical buildings, we are dealing with a situation in which empirical data required by the modeling process is either limited or altogether absent. This means that the assessment of such parameters should account for uncertainty.

The concepts of including uncertainty in assessing the parameter of the duration of a modeled project with the use of networks with an undetermined structure were first developed by H. Itakura and Y. Nishikawa [25]. They developed the concept of FGERT (Fuzzy Graphical Evaluation and Review Technique), which featured fuzzy data based on fuzzy logic introduced by L.A. Zadeh [26], E. Radziszewska-Zielina [27], E. Radziszewska-Zielina and B. Szewczyk [28]. C.H. Cheng [29,30], as well as Liu et al. [31] followed this concept, introducing triangular membership functions to the description of the uncertainty of the duration parameter within the network model. M.H.K. Gavareshki [32] introduced the trapezoid shape of the membership functions, which increased the scope of the modeled uncertainty of the abovementioned parameter. This concept is being further developed by S.S. Hashemin [33], G. Norouzi et al. [34]. However, the above-mentioned concepts are limited to modeling the uncertainty of only a single parameter of a network model - the duration of the performance of the activity of a planned project. The probability of carrying out the activities that are modeled by the network is defined as a deterministic value. Recently - in an alternative manner to the methods of modeling uncertainty parameters within stochastic network models that use type-1 fuzzy logic – there has emerged a concept involving the use of type-2 fuzzy logic. This concept is based on the introduction of additional fuzziness of the membership functions of the parameters that are being described. This allows us to better model the uncertainty of the parameters in question. I. Kutschenreiter-Praszkiewicz [35] introduced such a concept of modeling the uncertainty of one of the parameters of a network model - the probability of the performance of an activity - into a stochastic network. C.N. Wang et al. [36], by using the methodology of J.R. Chang et al. [37], use type-2 fuzzy

Table 1
The six possible two-element network combinations.
Source: [12].

receiver / emitter	AND	inclusive-or IOR	exclusive-or EOR
deterministic			
stochastic			