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Group decision-making in civil engineering based on AHP and PROMETHEE methods

Key words: group decision-making, project management, outranking methods, AHP, PROMETHEE

Introduction

Project management in the construction industry is generally based on a detailed decision analysis, as the decisions made today are crucial for achieving project goals in the future. This is particularly important in early project phases without reducing the importance of decision-making throughout the project life-cycle. Fundamental reasons for the existence of decision-making problems in civil engineering arise from: specific conditions of the construction industry (the final products are inseparable from the location, i.e. the location has a strong influence on the building design and its structural characteristics as well as on the technology used during construction), the wishes and attitudes of investors, and the influence of socio-economic and environmental aspects. Therefore, as Marović and Hanak (2017) argued, decision-making can be considered a critical success factor in construction management, as decisions drive projects from start to finish. To solve such problems, the multi-criteria decision-making methods (MCDM), such as analytic hierarchy process (AHP) and PROMETHEE, have gained increasing attention over the last two decades in the field of construction management as techniques to analyze complex situations and to support decision makers in their decisions. These two outranking methods are well used in the existing literature, where the decision problem in construction management is often viewed as single decision-making approach, but this is not the case with the group decision-making approach, where the environment of decision-making poses even more challenges. Therefore, this paper consolidates and discusses the current state of knowledge regarding the application of both methods against the background of the specifics of

the group decision-making in construction industry.

The main objective of this paper is to summarize the results of recent research articles on the application of the AHP and PROMETHEE methods as tools for group decision-making to achieve sustainability in civil engineering. Some of the other objectives have also been evaluated, such as (i) identifying specific problems and research areas where the above mentioned methods can help, and (ii) evaluating and highlighting the possible applications and their synergetic use.

Research methodology

In order to address how the existing body of knowledge in civil engineering has developed in the direction of group decision-making methods, in particular the AHP and PROMETHEE methods, a systematic literature review was conducted in this study. The research workflow was designed and developed (Fig. 1) in such a way that all relevant literature on a specific research topic can be identified, examined and evaluated at an early stage.

The conducted workflow of systematic literature review consists of three processes: data collection, literature analysis, and thematic discussion. The first step of data collection process was database selection, followed by data retrieval, and literature screening and supplement. In order to collect the most recent and relevant references, we decided to use renowned databases Scopus and Web of Science to get a global overview of the research topic. The search scope in those databases was restricted to the "Title/Abstract/Keywords" field. The collected contributions and subsequent reviews reflects papers published in peer-reviewed journals, preferably articles and reviews. To ensure the high quality and novelty of analyzed knowledge, only journal papers published between January 2000 and December 2019 were considered. The survey was conducted using selected keywords (group decision-making, multi-criteria, AHP, PROMETHEE, civil engineering, sustainable develop-

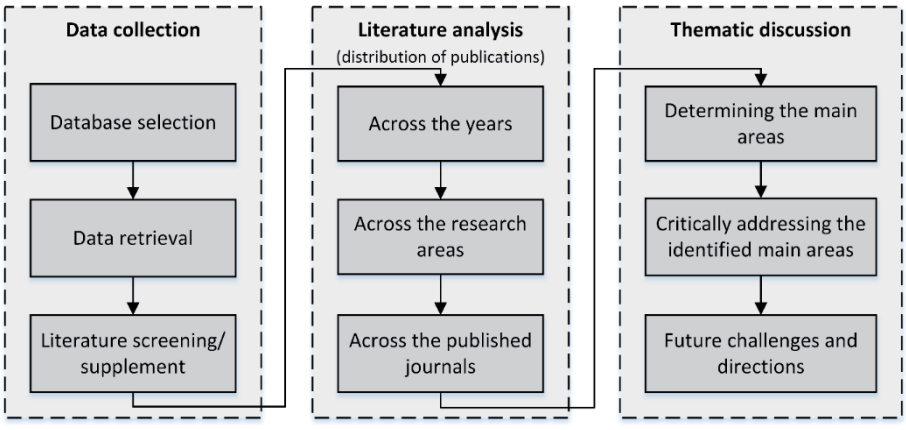

FIGURE 1. The systematic literature review workflow

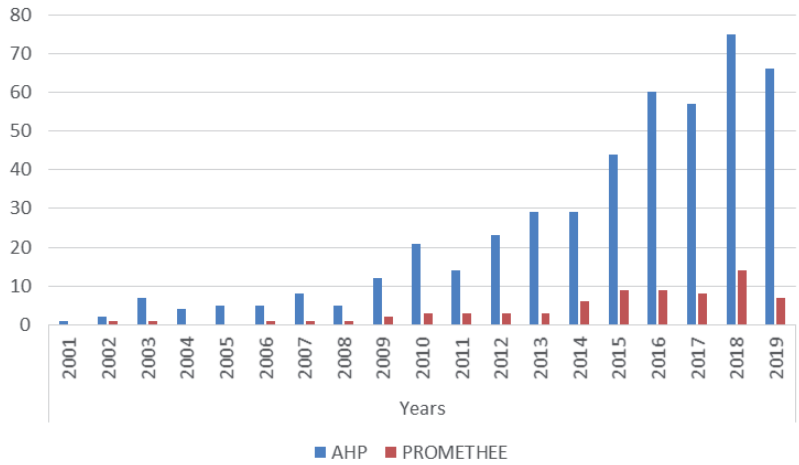

FIGURE 2. The distribution of AHP and PROMETHEE published papers from 2000 to 2019

ment), and their syntax derivatives. This resulted in two sets of papers:

– Set 1: Papers that consider the AHP method as a tool for group decision-making in civil engineering;
– Set 2: Papers that consider the PROMETHEE method as a tool for group decision-making in civil engineering

The literature screening/supplement was performed on all identified sets. During screening, both sets were checked in order to filter duplicates and off-topic ones. Then, a backward search (cross-referencing) was performed along the references to avoid missing important references. This led to the addition of several older references, and the possibilities of the synergic effect of the methods were discussed.

Concerning the first set, the conducted survey resulted in a total number of 503 (Scopus) and 443 (Web of Science) papers. As this paper focuses solely on group decision-making in civil engineering, a detailed analysis was carried out with regard to the decision support method, which allows a sustainable approach and/or sustainable development. For the second set 169 papers were found in Scopus and 78 in the Web of Science database. In addition, these sets were reduced by removing duplicities and papers that are outside the scope of this study. As the aforementioned clearly show, there is a large body of knowledge on group decision-making methods, but as far as papers related to civil engineering and sustainable development are concerned, the range of available literature is significantly narrower. The resulting number of studies that were included in a detailed investigation dropped significantly to a total of 463 (AHP) and 136 (PROMETHEE) papers. This procedure enabled grouping the thematically similar papers from the entire body-of-knowledge before the in-detail literature analysis.

The literature analysis process consists of two-step analysis: (1) the statistical distribution of collected publications across the year of publication, (2) their distribution across the research areas, and (3) published journals. The number

of identified publications and their corresponding year of publication are summarized in Figure 2. The following conclusions can be drawn from this brief overview: (i) that there is a significant difference in their application and publication between these two outranking methods in the years 2000–2019, and (ii) that both methods have been used more widely by the research community over the last 10 years.

The majority of the published papers are oriented towards Business, management and accounting, Environmental science, Engineering, Social sciences and Energy research areas. These research areas are harmonized with the Scopus research areas. All considered publications are published along with a huge number of journals indexed in the Scopus and Web of Science databases. Following are several journal names with the most published scientific papers: Sustainability (21 papers), Expert Systems with Applications (15 papers), Economic Research (10 papers), Energy (9 papers), Water Resources Management (9 papers), International Journal of Multicriteria Decision Making (8 papers), Land Use Policy (8 papers), Mathematical Problems in Engineering (8 papers), Resources, Conservation and Recycling (6 papers). Other journals published five or fewer papers on the subject topic and their number exceeds 200.

The final process of the conducted research workflow based on analysis and synthesis method, named "Thematic discussion" consists of three steps: (1) determining the main areas, (2) critically addressing them, and (3) identifying future challenges and directions. The synthesis of the conducted research is presented in the following sections.

Results and discussion

Over the last 20 years there have been numerous papers dealing with decision-making and the AHP and PROMETHEE methods covering various areas of civil engineering, such as road management, water management, waste management, construction site location selection, building design, facility refurbishment, logistics, etc. In addition, an overview of both methods has been published from time to time. For example, Danesh, Ryan and Abbasi (2015) presented a detailed literature review of the AHP method including its advantages and disadvantages, while Darko et al. (2019) gave an overview of the AHP application in the construction industry or specifically civil engineering (Deluka-Tibljaš, Karleuša & Dragičević, 2013). The most recent literature review of the PROMETHEE method with application in the civil engineering was given by Marović (2020). Unfortunately, in none of these reviews was much attention paid to the problem of group decision-making.

Overview of the AHP as a tool for group decision-making in civil engineering

The solution to the problem of determining the best location or the best construction site for individual facilities is very popular with researchers. Some of the authors who have also dealt with this problem are, Cheng, Li and Yu (2005), Ishizaka and Labib (2011), Jajac, Bilić and Mladineo (2012), Wang, Shen, Tang and Skitmore (2013), Jeong, García Moruno and Hernández Blanco (2013),

Abdullahi, Mahmud and Pradhan (2014), Jajac, Marović and Hanak (2015), Jeong, García Moruno, Hernández Blanco and Jaraíz Cabanillas (2016), Güler and Yomralýoğlu (2017), Marović and Hanak (2017). The facilities for which they were looking for the best location are diverse and include different types of power plants, hospitals, shopping malls, wastewater treatment plants, tourist facilities, landfills, parking areas, etc. The AHP is most often used in combination with GIS, (Jajac et al., 2015; Marović, Završki & Jajac, 2015; Kilić, Jajac & Marović, 2018), which has proven to be a very good solution for such complex decisions.

Choosing the best alternative when designing a new facility or reconstructing an old one is also a problem that is widely discussed in the literature. Hence, Nassar, Thabet and Beliveau (2003) has developed a system that helps to make appropriate decisions about the assemblies to be used in the various building elements. This decision has a significant impact on the performance of the building in relation to the various design criteria and AHP is used to determine the relative importance weights of these criteria. Similarly, Marović, Car-Pušić and Hrvatin (2014) developed a model based on AHP to evaluate public administration projects. At the scale of single project, Macieira, Mendonca, Miranda, Guedes and Tereso (2019) presented an efficient solution for refurbishment with architectural membranes, while Hsieh, Lu and Tzeng (2004) used fuzzy logic to determine the weightings of the evaluation criteria among decision-makers for selecting planning and design alternatives in public office buildings. The choice between two HVAC system designs by Hopfe, Augenbroe and Hensen (2013) led to practical way to jointly evaluate design options based on stakeholder's preferences and taking into the account the uncertainties associated with the designs.

In the field of road construction and management, Khademi and Sheikholeslami (2010) combined Delphi and AHP to develop decision-making tool for low--class roads maintenance programs. Their method can be useful in the context of decision-making at government agencies where decisions for all types of road facilities (pavement, bridges, traffic signs, etc.) are made together in one framework. Road maintenance has also been addressed by Jajac, Knezić and Marović (2009), Jajac et al. (2015) as they dealt with the pavement condition assessment. Using a case study of pavement condition, a flexible method is proposed that can accommodate the complexity of different roads. Similarly, Kušar and Šelih (2017) presented the development of a multi-criteria decision model based on AHP. Their model can be used in the planning and selection of passes within the national road network that intersects with a highway.

In the water management area the AHP method is mostly used as one of decision tools in decision support systems for selecting the best plan alternatives in the environment watershed (Chen et al., 2011), identifying flood-prone areas (Arabameri, Rezaei, Cerdà, Conoscenti & Kalantari, 2019), managing flood disasters (Nivolianitou, Synodinou & Manca, 2015), wastewater treatment plants (Jajac, Marović, Rogulj & Kilić, 2019), etc. Also, Ahmad and Verma (2018) ap-

plied AHP in combination with remote sensing and GIS to identify the most suitable water storage site. They all pointed out that the integration of AHP and GIS could be useful in decision making and in handling large data for effective water resources management.

The problem of making design decisions from an energy-saving and environmental perspective was handled by Liu, Hsueh, Wu and Chen (2012) with goal to provide a type of construction that can effectively provide high energy--saving building designs. Prioritization of large infrastructure projects handled Ziara, Nigim, Enshassi and Ayyub (2002) showed synergy of the Delphi technique and AHP as a framework for prioritization of urban infrastructure projects that are based on project deliverables and project life-cycle and implementation guidelines.

All authors highlighted the importance of reaching consensus in case of a synergistic group i.e. stakeholders. In other case, mathematical aggregation is mandatory. Regarding their research areas, all authors perform aggregation uniformly both at the comparison level and at the priorities level.

Overview of the PROMETHEE as a tool for group decision--making in civil engineering

The PROMETHEE is an outranking method for a finite set of alternative actions to be ranked and selected among criteria, which are often conflicting (Behzadian, Kazemzadeh, Albadvi & Aghdasi, 2010). The method requires very clear additional information that is easily obtained and understood by both decision-makers and analysist (Brans & de Smet, 2016), and therefore is widely used in helping to solve civil engineering problems in more sustainable way.

Hence it is often used in the energy sector, to achieve sustainable energy development, where transition to investment and production of renewable energy sources is necessary. Some of the transition strategies include decarbonization of energy system, development and deployment of low-carbon technologies, acceleration of energy productivity improvement and falling fossil fuel use. Mardani, Jusoh, Zavadskas, Cavallaro and Khalifah (2015) emphasized use of MCDM in energy system options, planning, management, and the economy is helpful to energy systems development as well as evaluating their sustainability. Thus regarding multi-criteria and group decision-making, some of the researchers use PROMETHEE method to evaluate and prioritize the energy system considering a wide range of environmental, economic, technical, political and social criteria. Therefore, Papapostolou, Karakosta, Kourti, Doukas and Psarras (2019) presented multi-criteria approach based on an extension of the PROMETHEE method for group decision-making that incorporates fuzzy set theory in order to evaluate alternative transformation pathways for achieving a sustainable energy system while Soni, Singh and Banwet (2016) prioritize energy sector projects, namely, coal, gas, hydro and solar using the MCDM outranking approach of PROMETHEE under a fuzzy environment.

Building and construction management is another field in civil engineering where some researchers propose

their MCDM based models for solving complex decision-making problems. Balali, Zahraie and Roozbahani (2014) developed an algorithm combining two MCDM methods, namely, ELECTRE III and PROMETHEE II for ranking of structural systems, while Marović et al. (2015) gave a group decision support concept based on synergic effect of AHP and PROMETHEE based on GIS. Such followed by Kilić et al. (2018) as they described and tested their research based on the establishment of GIS-based decision support for the planning of land acquisition for the realization of urban public projects, while Jajac, Rogulj and Radonić (2017) presented a decision support concept for the management of rehabilitation projects during the planning phase, using PROMETHEE and AHP methods.

The MCDM can provide solutions for complicated water infrastructure management decision-making problems. For example, Inamdar, Sharma, Cook and Perera (2018) developed a comprehensive methodology framework for evaluating stormwater harvesting sites in urban areas using MCDM. In their research, the decision analysis methodology broadly consisted of deriving PROMETHEE rankings of eight alternatives, under two distinct group decision-making scenarios. Alhumaid, Ghumman, Haider, Al-Salamah and Ghazaw (2018) evaluate stormwater drainage options for urban areas of arid regions using MCDM on the basis of four sustainable criteria, i.e., flood risk, economic viability, environmental impacts, and technical constraints. In their research, criteria weights were established through group decision-making using both AHP and PROMETHEE. Silva, Morais and Almeida (2010) presented a tool to support the committee responsible for the management of the watersheds in order to promote decentralization and the participation of all involved in water resources management.

The method is also effective considering field of road, transportation and logistics management such as maintenance management of road infrastructure (Jajac et al., 2009), selection of the optimal toll collection system (Milenković, Glavić and Mladenović, 2018), as well as location selection of a multimodal logistics center (Pamučar, Tarle and Parezanović, 2018). They highlighted that PROMETHEE can offer consistent solutions and have a stable and well-structured analytical framework for ranking the alternatives. Macharis, de Witte and Ampe (2010), Macharis, Turcksin and Lebeau (2012) proposed a group decision support system as a tool to support sustainable decisions in transport projects, while Sarrazin and de Smet (2015, 2017) applied a multi-criteria clustering technique based on PROMETHEE to carry out an integrated and preventive assessment of road projects at their design stage.

Regarding their research areas, all authors perform either scenario ranking (where scenario represents group consensus) or two-step ranking approach (individual ranking of each involved stakeholder then group ranking based on the previously aggregated values).

Synergy of both methods in achieving sustainability in civil engineering

It is evident that many researchers combined both the AHP and PROMETHEE method or additional methods in order to achieve the most appropriate and sustainable solution in their field of interest. Such became more of use since 2004, when Macharis, Springael, de Brucker and Verbeke (2004) proposed model based on the idea of combining PROMETHEE and AHP whose synergy effect is most evident during the decision-making hierarchy setup. Since, many researchers used the synergic effect of these methods in order to solve their research problem in more sustainable way and can be found in building and construction management, road transportation and logistics management, energy management, water infrastructure management, etc.

Many combined AHP and PROMETHEE with other MCDM methods, but also introduced fuzzy logic to both methods. Especially interesting is the fact that almost all researchers suggest the use of GIS with both methods as a platform for visual representation of group decision-making in civil engineering.

Conclusions

Both AHP and PROMETHEE has become a popular methods for organizing, analyzing, and modelling complex decisions within the civil engineering. This paper attempted to review both methods in support group decision-making as to improve understanding of the decision areas and decision problems that could be efficiently resolved in more sustainable manner. The findings revealed that, although popular, both methods has still lot to offer in group decision-making in civil engineering.

This paper could be useful for researchers and practitioners interested in the application of AHP and PROMETHEE to analyze and model their decisions in managing construction projects. For researchers, this paper provides a comprehensive review of past studies during last two decades, which is necessary for conducting future studies. In addition, this paper could help practitioners better understand and judge the usefulness of AHP and PROMETHEE in tackling specific decision-making problems in civil engineering.

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Summary

Group decision-making in civil engineering based on AHP and PROMETHEE methods. The Analytical Hierarchy Process (AHP) and PROMETHEE have gained increasing attention in the field of construction management as techniques for the analysis of complex situations and as decision support for decision makers. However, these two methods in themselves or their potential applications to problems of construction management are not sufficiently defined in the existing literature. The environment of group decision-making bring even more challenges. This paper consolidates and critically discusses the current knowledge on the application of AHP and PROMETHEE methods in the light of the specifics of the construction industry. A systematic literature review was used to select the contributions indexed in the databases Scopus and Web of Science. The findings indicate that the studies deal with broad topics and different aspects in different phases of civil engineering projects. This paper provides a useful reference work for researchers and practitioners interested in the application of AHP and PROMEETHEE as tools for group decision-making in civil engineering.

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