Application of Fuzzy Analytical Hierarchy Process for Revising OIU Main-Campus Masterplan to Ensure Sustainable Environment

Eltayeb H. Onsa Elsadig, Ghassan M. T. Abdalla, Muna Mustafa Eltahir, Gasim Hayder, Abderrahim Lakhouit, Isam M. Abdel-Magid, Hisham I. Abdel-Magid, Anis Ben Messaoud, Ahmed H. A. Yasin, Omer A. Sayed, and Mohamed B. Elsawi

Abstract

Omdurman Islamic University is one of the oldest universities in Sudan. OIU campus masterplan (CMP) was first developed in 1978 and revised in 2002. Yet too many important parts of the revised CMP need to be redesigned and constructed. Revising the existing university masterplan is complicated and needs to be tackled carefully in the light of new conceptual criteria without affecting the ongoing educational, research, and administrative activities. Furthermore, for the sustainability of the facilities to be increased, there are key approaches, namely, environmental-friendly materials, environmental-friendly landscape, safety, conservation of energy, and extended operation life. The Fuzzy Analytical Hierarchy Process (FAHP) is to solve multi-level and complex decision-making problems in a systematic approach. Based on experts' judgment on several design alternatives and criteria in addition to sub-criteria. The opinions are compared in a pairwise fashion based on three expertise and three decision-makers as the criteria and sub-criteria to assess how their contribution to the target. This paper aims at building a new assessment framework for sustainable CMP to be later applied to the case study of OIU main campus in Sudan. To assess the proposed CMP in terms of sustainability, three sustainable alternatives (A1, A2, and A3) are proposed, along with four criteria and 13 sub criteria (factors). The alternatives are studied for the best alternative selection. Each of the criterion and factor weight is calculated using the FAHP. The analysis result shown a rational procedure which utilizes successfully the use of FAHP to help the decision processes for the OIU revised CMP.

Keywords

University campus • Masterplan • Fuzzy analytical hierarchy process • Sustainable environment • NEOM

Highlights

1. A method for developing a new assessment framework for a sustainable campus master plan was devised and used to a case study.
2. An environmental, economic, ecological, and management criterion framework was proposed.
3. As a case study, the Omdurman Islamic University choices were adopted.
4. The relevance of weighting on alternative selection is reflected in sensitivity analysis.

1 Introduction

1.1 About Omdurman Islamic University

Omdurman Islamic University (OIU) is the name of the former Omdurman Scientific Institute (OSI). The OSI is one of the foremost private scientific institute established in Sudan, which have been graduated many personalities and prominent scholars from it. The colonial government at that

E. H. O. Elsadig (✉) · A. Lakhouit · A. B. Messaoud · M. B. Elsawi
Department of Civil Engineering, Faculty of Engineering, University of Tabuk, Tabuk, Kingdom of Saudi Arabia
e-mail: e.onsa@ut.edu.sa

G. M. T. Abdalla · A. H. A. Yasin · O. A. Sayed
University of Tabuk, Tabuk, Kingdom of Saudi Arabia

M. M. Eltahir
Omdurman Islamic University, Omdurman, Sudan

G. Hayder
Department of Civil Engineering, College of Engineering, Universiti Tenaga Nasional (UNITEN), 43000 Kajang, Malaysia

I. M. Abdel-Magid
Elrazi University, Khartoum, Sudan

H. I. Abdel-Magid
Lirio Academy, London, UK

G. H. A. Salih and R. A. Saeed (eds.), *Sustainability Challenges and Delivering Practical Engineering Solutions*, Advances in Science, Technology & Innovation, https://doi.org/10.1007/978-3-031-26580-8_15

time has been asked by Sudanese scholars to establish the OSI which has been agreed and established in the year 1912. The OSI in Sudan resembles the Egyptian Al-Azhar religious education system. The OSI was upgraded until later became Omdurman Islamic University in 1965.

The built area of the OIU campus is approximately 800 acres (3360 km^2) in Omdurman city near the left bank of the White Nile. Besides oriented as a primarily Islamic studies, it is also serves other fields of studies as well, such as agriculture, engineering, medicine, and many more. It is worthwhile mentioning that OIU is a federation member of the universities of the Islamic World.

The first masterplan for OIU campus was approved around 1978. This MP adopted the ring-orientation of all buildings: OIU administration, main library, main mosque, and auxiliary premises were located at the center; the faculties and institutes spread around the ring having common radial orientation towards the center.

Until 2000, only small parts of the approved OIU first MP were executed, so it became inevitable to revise the campus MP. In 2002, the Faculty of Engineering Sciences at OIU proposed a revised MP for the campus in which a wide ring road was proposed with all the educational and administrational premises lies on the left and right sides of the ring road. Recently, in 2015, some updates were introduced to the 2002 MP. Figures 1, 2, 3 and 4 and Table 1 show the progress in executing OIU MP for the years 2004, 2011, and 2021.

It seems none of the above OIU MPs ensures sustainable environment, an issue that became vital for any educational campus planning nowadays. Waste minimization transportation demand management, energy production and consumption, building construction, academic integration of sustainability, purchasing, water systems, and more are the examples of the Sustainability issues.

Fig. 1 OIU campus—2004 (*Google earth* ©)

Fig. 2 OIU campus—2011

Fig. 3 OIU campus—2021

The Fuzzy Analytical Hierarchy Process (FAHP) is broadly used as the multi-criteria decision-making methods (MCDM). In any decision-making and planning process, a systematic and logical approach is to be used to reach at solutions. In MCDM analysis, the most common method is the fuzzy set theory to deal with uncertainties Pedro Moura et al (2021), Michigan State University (2021), University of Colorado Boulder (2021).

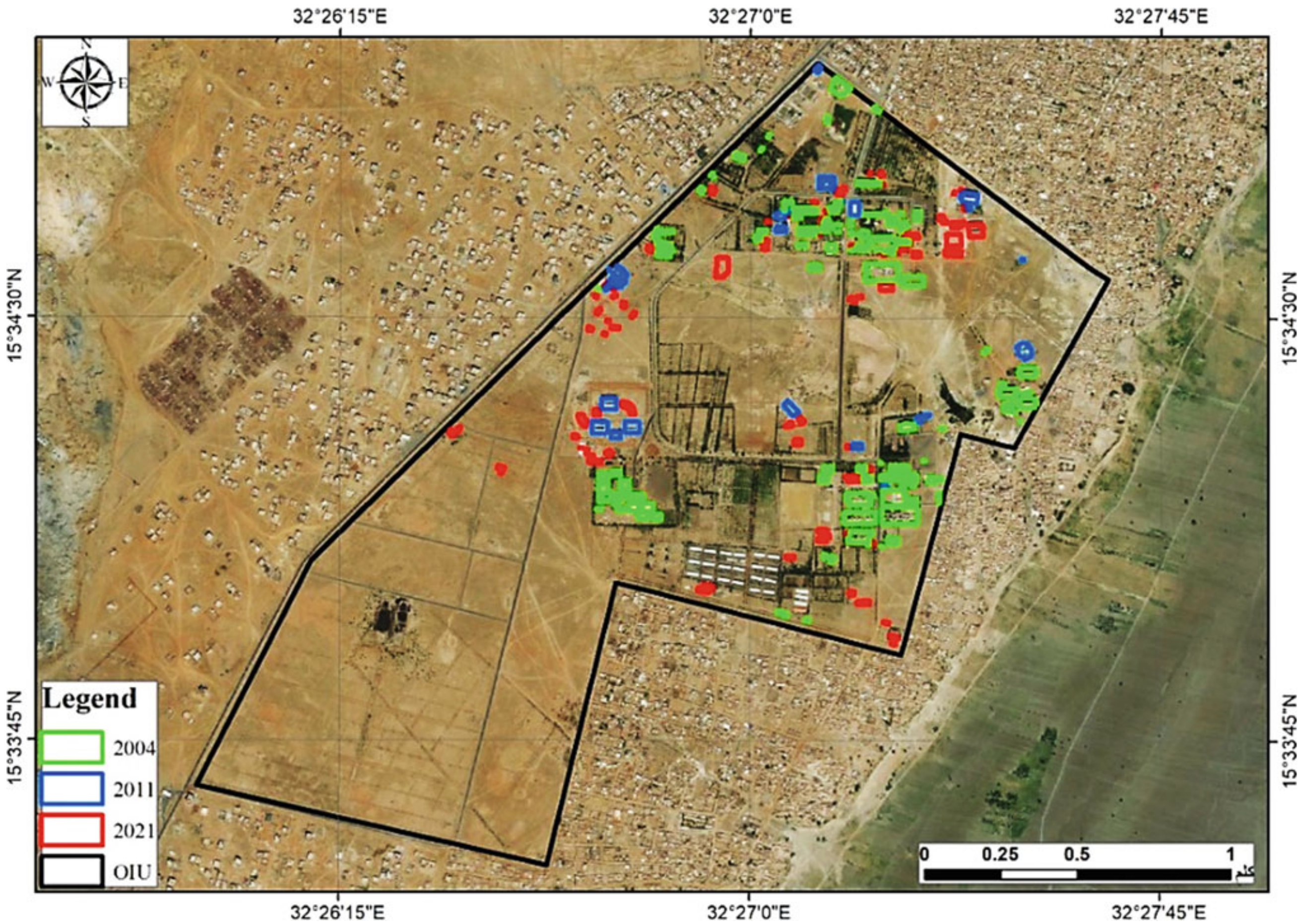

Fig. 4 Summary of the progress in executing OIU campus MP for years 2004–2021

Table 1 Progress in built area at OIU main campus

Year	Built area (m^2) *not including open space and roads*
2004	134,500
2011	166,000
2021	206,700
Expected in new MP	450,000

The decision-making for selection between different designs options of re-plan of existing university masterplan is not easy in the existence of several affecting criteria. The research objective is to develop FAHP for selection between design alternatives of OIU MP. The developed process will depend on intuitionistic fuzzy sets, on way to assist OIU decision-makers to decide and select the most appropriate design considering the environmental sustainability.

The opinion of experts and decision-makers is pairwise analyzed for the selection between the design alternatives. A questionnaire is designed and analyzed using most recent FAHP approaches. The group of evaluations weights is studied using spreadsheets established by the researchers.

1.2 Justification

Why re-planning of OIU main campus masterplan (MP)? the reasons are:

- Existing OIU main campus masterplan was more than 20 years old.
- More than half of the components of OIU main campus (MP) yet need to be implemented.
- OIU need to compare the present alternatives and see how to reduce the environmental impact of material, operation, and design.

2 Methods

2.1 Analytic Hierarchy Process (AHP)

The AHP system is first introduced by Satty (1980). In AHP, categories to compare between different alternatives are identified and given relative weights by evaluators. The

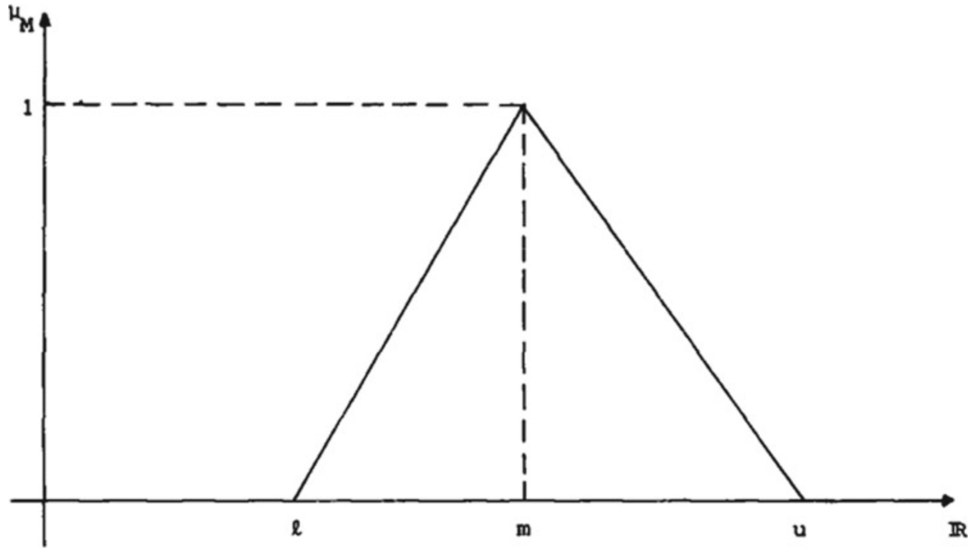

Fig. 5 Triangular member function

alternatives are then given a score for each of these categories. The best alternative is then identified by calculating a weighted sum for each alternative and selecting the alternative with the highest score. The main problem with AHP is the integer ranking process (1–9) since the evaluator must select a definite value for each category/alternative whereas his opinion might be anything within a range. These definite values might even accumulate and lead to sub-optimal selection. To overcome this limitation, Laarhoven proposed the use of fuzzy numbers for the ranking process (van Laarhoven and Pedrycs 1983). Fuzzy numbers are not definite (crisp) values. They define an interval or range that belong to a certain category (rank). A member function identifies how strongly related each value belongs to an interval. Laarhoven used fuzzy numbers with triangular member functions as defined in Eq. (1) and shown in Fig. 5 for the ranks. Each rank is defined by three parameters: the lower limit l_i, the modal m_i, and the upper limit u_i (Table 2). In the member functions, only the modal is related to the rank with value (relation) 1. The intervals [l, m] and [m, u] are shared by previous and subsequent ranks.

$$\mu_M(x) = \begin{cases} \frac{1}{m-l}x - \frac{l}{m-l}, & x \in [l, m] \\ \frac{1}{m-u}x - \frac{u}{m-u}, & x \in [m, u] \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

Using these ranks, van Laarhoven and Pedrycs (1983) developed linear equations to calculate the lower, modal, and upper limits from the experts' response. However, a unique solution was not always possible using his method.

Buckely proposed the use of geometric mean to implement FHAP (Buckely 1985). If evaluations from several experts are available, the geometric mean of their evaluations is used for comparison. Assuming trapezoidal member functions, Buckley derived the member function for the alternative and then used α cuts to compare two alternatives each time. The alternatives are then classified in descending

Table 2 AHP and FAHP weights

Intensity of Importance/Evaluator decision	AHP Weight (i)	FAHP Weight (l, m, u)
Equal Importance (EI)	1	(1,1,1)
Equal to Moderate Importance (EMI)	2	(1,2,3)
Moderate Importance (MI)	3	(2,3,4)
Moderate to Strong Importance (MSI)	4	(3,4,5)
Strong Importance (SI)	5	(4,5,6)
Strong to Very Strong Importance (SSI)	6	(5,6,7)
Very Strong Importance (VSI)	7	(6,7,8)
Very Strong to Extreme Importance (SEI)	8	(7,8,9)
Extreme Importance (ExI)	9	(9,9,9)
Reciprocity property	1/i	(1/u, 1/m, 1/l)

order. Nang extended this method by using center of gravity to calculate decision weights (Nang-Fie 2008). His algorithm produces three decision matrices (lower bound, most likely, and upper bound) to reflect three levels of uncertainty.

The most widely used algorithm is the one developed by Chang (1996). Chang used extent analysis to develop an algorithm to compare fuzzy numbers and calculate the weights for criteria and alternatives assuming triangular fuzzy member functions. If there is more than one evaluator, the average of their evaluations is calculated first, then the sum (S_i) of each row in the evaluation matrix is calculated and divided by the sum of the matrix. Based on the modal value (m_i) of the sum, the degree of possibility that S1 $\geq$ S2 is calculated by:

$$V(M_1 \geq M_2) = 1 \quad \text{iff } m_1 \geq m_2$$
$$V(M_2 \geq M_1) = \text{hgt}(M_1 \cap M_2) = \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - u_1)} \quad (2)$$

The weight vector is then calculated by:

$$W' = (\min(V(S_1 \geq S_2, S_3, S_4, \ldots)), \min(V(S_2 \geq S_1, S_3, S_4, \ldots)), \min(V(S_3 \geq S_1, S_2, S_4)), \ldots) \quad (3)$$

$$W = \frac{(w_1, w_2, w_3)}{\sum(w_i')} \quad (4)$$

Modifications to Chang's algorithm have been proposed in Enea and Piazza (2004) and Klir (1997) to include constraints on the numbers of fuzzy and improve the criteria weights; however, in several cases, they produce identical results to Chang's algorithm.

2.2 The Design Alternatives

Three design alternatives will be studied to choose the most appropriate alternative for re-planning OIU MP. Each alternative shall ensure sustainable environment. The alternatives are:

A1: Consider Omdurman city planning characteristics.
A2: Consider Islamic planning approach.
A3: Follow modern trends in university campus planning.

The impact of each alternative is expected to be reflected on the performance in OIU main campus and the life pattern of the surrounding areas, the local economy and environment, and other issues might render the officials to think in depth to decide and answer the question: ***which of the above mentioned three design alternatives is most appropriate?***

The measuring criteria are complex and are not so clear or predetermined for such kind of decision-making procedure. Expert engineers/architects shall help the decision makers to follow a philosophy and analyze the situation and, thereby, create suitable criteria giving him evidence that the selected criteria shall strictly lead to the appropriate decision (Alyamani and Long 2020; Heo et al. 2021; Balioti et al. 2018).

2.3 Establishing Criteria and Factors (Sub-criteria)

In establishing the main criteria, the following general principles shall always be acknowledged: arrange campus buildings, circulation, open space, and utility systems to: establish positive interactions among academic, cultural, outreach, research, and operational activities. Also, the campus shall create a life-learning resource integral to the OIU vision.

Criteria involved in universities CMP and re-planning generally include the following four principles which were chosen to be the main criteria for re-planning OIU CMP: Circulation; Environmental sustainability; Land use and facilities; and Cost. Furthermore, each criterion has influencing factors (sub criteria) as shown in Table 3.

Description of sub-criteria

C_{11} Implementation of compact campus development:

Benefits to be achieved are: protect and preserve existing facilities, natural areas, and systems to support research and teaching; conserve land, optimize land productivity; strengthen ties between undergraduate teaching and research; and link campus with neighboring areas.

C_{12} Recognition of historically significant aspects:

Recognize historically important aspects of OIU campus and its heritage as learning laboratory and a living and a park.

C_{13} Acknowledgment of existing facilities:

Renovations and new buildings design to be architecturally harmonious with their contextual surroundings and compatible with the existing adjacent buildings best features.

C_{21} Optimize environmental impacts:

By minimizing the impacts on the environmental and maximizing conservation of the resource through compact land use and wise use of building materials, integrate

Table 3 Criteria and sub criteria

Criteria	Sub criteria (Factors)
C_1: Land use	C_{11} Implementation of compact campus development
	C_{12} Recognition of historically significant aspects
	C_{13} Acknowledgment of existing facilities
C_2: Environmental sustainability	C_{21} Minimizing the environmental impacts
	C_{22} Encourage renewable resource
	C_{23} Recognizing climate vulnerability
	C_{24} Construction materials to be (eco-friendly)
C_3: Circulation	C_{31} Setting circulation priorities
	C_{32} Emphasize personal safety
	C_{33} Providing effective transportation network
C_4: Cost and financial aspects	C_{41} Availability of fund
	C_{44} Cost of construction and furnishing
	C_{43} Cost of operation

development guidelines with low-impact, and protecting environmental systems.

C_{22} Encourage renewable resource:

Continuously attempting building and utility systems that decrease hazardous materials and waste and encourage the use of renewable resource.

C_{23} Recognizing climate vulnerability:

By attempting land use issues associated with climate vulnerability e.g., temperature extremes management and storm water.

C_{24} Construction materials (eco-friendly):

Using the green materials. It means new materials of construction with few emissions and environmental impacts.

C_{31} Setting circulation priorities:

Design and plan for the following circulation priorities: Incorporate traffic-calming measures where appropriate.

C_{32} Emphasize personal safety:

Assuring safety of the personal in the circulation system's design and planning.

C_{33} Providing effective transportation network:

Design and plan for the following circulation priorities: firstly pedestrians; secondly non-motorized transportation; thirdly mass transit and service vehicles; and lastly private vehicles.

C_{41} Availability of fund:

Assuring to what extent the MP implementation fund will be available according to a desirable disbursement plan.

C_{42} Cost of construction and furnishing:

Optimizing the total cost of: new constructions, rehabilitation of old facilities including all furniture, equipment, services, etc.

C_{43} Cost of operation:

Setting proper implementation management system.

3 Results

3.1 Weights of the Criteria

Table 4 presents the weights of the criteria obtained from the opinion of the experts. Table 5 gives the weights of the same criteria as depicted from the opinion of the decision-makers.

Table 4 Weights of the criteria —Experts' opinion

Criteria	C_1	C_2	C_3	C_4
Weight	0.2319	0.2401	0.2225	0.3055

Table 5 Weights of the criteria—Decision-makers (DMs) opinion

Criteria	C_1	C_2	C_3	C_4
Weight	0.2188	0.2040	0.2040	0.3728

Table 6 Weights of the sub criteria (factors)—Experts' opinion

Criteria	C_1			C_2			
Sub criteria	C_{11}	C_{12}	C_{13}	C_{21}	C_{22}	C_{23}	C_{24}
Weight	0.3401	0.3284	0.3315	0.2431	0.2452	0.2374	0.2743

Criteria	C_3			C_4		
Sub criteria	C_{31}	C_{32}	C_{33}	C_{41}	C_{42}	C_{43}
Weight	0.3401	0.3284	0.3315	0.3322	0.3345	0.3333

Table 7 Weights of the sub criteria (factors)—Decision-makers (DMs) opinion

Criteria	C_1			C_2			
Sub criteria	C_{11}	C_{12}	C_{13}	C_{21}	C_{22}	C_{23}	C_{24}
Weight	0.3382	0.3378	0.3240	0.2514	0.251	0.2493	0.2483

Criteria	C_3			C_4		
Sub criteria	C_{31}	C_{32}	C_{33}	C_{41}	C_{42}	C_{43}
Weight	0.3339	0.3339	0.3322	0.3341	0.3329	0.3329

3.2 Weights of the Sub Criteria

Tables 6 and 7 present the weights of the sub-criteria obtained from the opinion of the experts and the decision-makers, respectively.

3.3 Alternatives Scores

Tables 8 and 9 present the alternatives scores obtained from the opinion of the experts and the decision-makers, respectively, see also Figs. 6 and 7.

4 Discussion

The cost criterion (C_3) received the highest weight from opinion of the experts and DMs, while the environmental sustainability criterion (C_2) came in second rank.

The weights of the factors (sub criteria, C_{ij}) for each criterion are found more-or-less not differing much from each other. This result is probably due to the limitation of linguistic diversity of selection.

Assessing the three design alternatives, both the experts and DMs gave the highest scores to the re-planning of OIU

Table 8 Alternatives scores—Experts' opinion

Alternatives	Criteria				Overall scores
	C_1	C_2	C_3	C_4	
A1	0.2744	0.3364	0	0.3644	0.350775
A2	0.2711	0.3364	0.4762	0.2713	0.248497
A3	*0.4545*	*0.3273*	*0.5238*	*0.3644*	*0.400327*

Table 9 Alternatives scores Decision-makers (DMs) opinion

Alternatives	Criteria				Overall scores
	C_1	C_2	C_3	C_4	
A1	0.2967	0.4032	0.3844	0.3358	0.255727
A2	0.2880	0.2932	0.1588	0.2502	0.332474
A3	*0.4152*	*0.3036*	*0.4569*	*0.4140*	*0.411853*

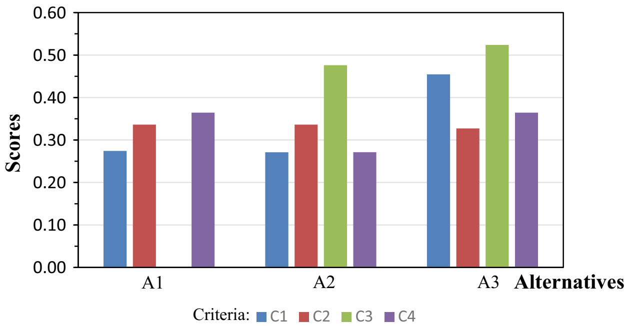

Fig. 6 Alternatives scores—Experts' opinion

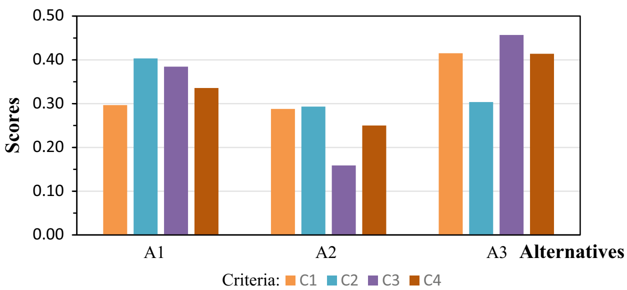

Fig. 7 Alternatives scores—MDs' opinion

main campus MP following the modern trends in university campus planning (A3).

5 Conclusions

The current research implements the FAHP method as a MCDM approach to establish a sustainable selection tool that quantifies four key sustainable criteria based on priorities. The tool can be used by decision maker or expert architect during the evaluation of several alternatives for re-planning university campus masterplan considering sustainable environment. The chosen criteria in this study are project cost, land use, environmental sustainability, and circulation. The criteria ranking is based on relative importance would help decision-makers and designers to identify university MP project features that require more consideration, better resources allocation, and to improve the evaluation of the sustainable options.

This research limitations include the literature sample size that considered to assist the experts and DMs the chosen criteria in the pairwise comparison. Also, the study results are influenced by the experiences and knowledge of the participated experts and decision-makers.

It is worthwhile mentioning that main campuses of OIU and University of Tabuk, KSA, look very similar regarding the size, current situation, execution progress, and general principles and requirements. Hence, the procedures stated in this research can possibly be applied to UT considering also the uniqueness of UT being part of NEOM, the most challenging project in KSA.

Acknowledgements The authors extend their appreciation to the Deanship of Scientific Research at University of Tabuk and to the Deputyship for Research and Innovation, Ministry of Education in Saudi Arabia for funding this research work through the project number S-1441-0165.

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