ISSN: 0974-5823 Vol. 7 No. 1 January, 2022

International Journal of Mechanical Engineering

Evaluation of the development of evaluation performance criteria of the sustainability of modular construction methods versus conventional methods

Abbas Jaen Seger Al-Dauod , Husam Ghazi Hadi, Ahmed Hussein Ali

Abstract

The modular construction method (prebuilt) has increasingly been used as a substitute for conventional construction over the last few years. The purpose of this study was to investigate the development of performance criteria for assessing the sustainability of modular construction methods versus conventional methods, in order to evaluate and compare the life cycle of modular construction with ordinary construction; dimensions of sustainability including environmental dimension (12 sub-criteria), economicaldimension (9 sub-criteria) and social dimension (12 sub- criteria) were used. The results of the analysis indicated that themost important dimensions of the development of performancecriteria for assessing the sustainability of modular construction methods versus conventional methods are economic dimension,social dimension and environmental dimension, respectively. Also, the most important factors for modular and conventionalconstruction differences are location selection, disturbance in location and appropriate strategies, renewable energy, energy efficiency and effective strategies, energy in the total process ofconstruction, water and sewage efficiency strategies, local materials, renewable materials, waste materials management, construction materials, time design and construction cost, operating and maintenance costs, final side costs, buildingsustainability, investments and related risks, flexibility, integrated management, residents' health and comfort, impact on the local economy, usability of physical space, building aesthetic, disruption and disturbance of the society, the impact on local social development, user acceptance and satisfaction, and local access and amenities.

***Keywords*—**Sustainability, Construction, Modular Method, Conventional Method, Performance Criteria

INTRODUCTION

The construction industry, like other industries, is constantly evolving. With the increasing competition in the field of construction and globalization, constructors have movedtoward the selection and implementation of advanced construction techniques. This method has been used extensivelyin other countries for a long time, but unfortunately, in our country, it is significantly unknown and sometimes even abandoned, due to the lack of recognition of these methods. The extent of the application of advanced construction techniques issuch that not only can reflect the ideas and imaginations of thedesigners, but also have a profound effect on the thinking and thought of architectures. One of the goals of this method is to objectify the ideas and imaginations of the designers and to implement their theories. Some people with suspicious on thesemethods, think and say that these methods cannot always be inline with the local, cultural and identity conditions of the different regions, and the disputes of this kind caused some suspicious in the above mentioned methods. Of course it shouldbe noted that some steps have been taken to address these issues. The pervasiveness and durability of any modern methodin today societies depends on the flexibility of these methods with factors such as culture, national identity of societies and compatibility with climate of those regions. Basically, the gapsin the advanced methods of construction and demand andrequirements in the design had not led to a lack of general meeting of this method, but over the time these disadvantages have been eliminated, as well as sustaining a new wave and creating new ideas in the field of construction. With the help ofadvanced construction techniques, many of the existing problems in the field of construction can be overcome and the needs and current trends in constructing processes can be transformed [1].

Sustainable construction deals with three dimensions of environmental, economic and social. Sustainable construction actually strikes a balance between sustainability dimensions byexamining related criteria to the life cycle of a construction project. The built environment and dependent processes significantly effect on the three-dimensions of sustainability. The specific goals of the projects, such as cost and time, are traditionally the focus areas of many studies in the past. At thesame time, due to increased awareness, the impact of the life cycle of buildings on the environment and society has increasedrapidly due to sustainability, and the "sustainable building" hasbecome an important factor in recent years [2].

Outside building construction processes have been used as alternatives to construction processes at the building site over the last few years. Prebuilt buildings are known as one of the main construction methods out of the building site, in which various prebuilt buildings are constructed at an industrial center(85-90 percent of the project work) and then transferred to the Emad Jabbar keshish

al-Mahmoud is with Civil Engineering Department, Ferdowsi University of Mashhad, Mashhad, Iran. Hashem Shariatmadar. is with Civil Engineering Department, Ferdowsi University of Mashhad, Mashhad, Iran.
location of final project to build a building [3]. This method hasmany advantages in comparison to its conventional counterpart; such as, reduce project time, increase production quality, and the others. At the same, using of prebuilt building is limited andlow. According to Wye and Woo [4], the negative environmental and financial effects, such as wasting the resources and oversteps of cost, are inappropriate for choosingthe construction methods.

Sustainability evaluation is for collecting and providinginformation to facilitate decision processes. Several methodsand systems have been developed to assess the sustainability ofbuildings. A significant category of sustainability evaluationmethods includes sustainable building grading systems. Sustainability grading systems address the sustainability ofbuildings. This is done by providing a set of performancecriteria and scoring each construction project based on thesecriteria. These systems examine the performance or expectedperformance of a "general building" and allow comparisons ofdifferent buildings. Despite its enormous advantages, thismethod has some disadvantages and deficiencies such ascomplexity and diversity of criteria (like energy modeling), thebureaucracy process of evaluation, and the high cost of usagepreventer (like comparative cost of evaluation and approval),etc. [5]. Another important category is to assess thesustainability (environmental) of buildings from life cycleevaluation systems or LCA-based tools. LCA-based tools wereoriginally developed to assess the environmental impacts of abuilding's lifecycle. They usually have a bottom-up approachthat combines the effects of building materials and componentsto reflect the environmental impacts of the overall building [6].Since the suitability of the prebuilt building is a matter of concern, a critical review was carried out by Kamali and Hiwaj[7], and they expressed that some studies have consistentlyevaluated the suitability performance of the life cycle ofprebuilt and conventional buildings. At the same time, theirmain emphasis was on assessing the environmental life cycle(LCA) and no studies were found on the field of evaluation ofthe economic life cycle or the social life cycle (SLCA) of thesebuildings. In addition, each study was limited to its region anddid not include the general life cycle or did not examine themost important criteria. The results of the above studiesemphasize that the use of prebuilt buildings can lead to fewerenvironmental effects than traditional and conventionalbuildings. At the same time, as previously mentioned, in a sustainable building, all applicable sustainability criteria andimportance should be sufficiently considered throughout theoverall life cycle. The most important step is to developsustainability evaluation criteria to assess the development ofthe sustainability of the life cycle of buildings (SEC). So, in theresearch, the researcher first identifies and validates theappropriate indicators for assessing the sustainability of the lifecycle of prebuilt modular and conventional buildings and then,determine the importance of sustainability performanceindicators for choosing a construction method, and finally ranksthe indicators of sustainability performance including environmental, economic and social dimensions.

At the rest of this paper in section 2, the background of research will be examined. In section 3, the research methodology will be presented. In section 4, the analysis of datawill be discussed and the last section presents the conclusion ofpaper.

RESEARCH BACKGROUND

In this section of research, the background of researches is provided briefly and importantly.

Alvaer and Clements Croum [8], in a research investigated and studied key performance indicators and prioritization criteria using a multi-index approach to assessing sustainable smart buildings. This research was conducted using a consensus-based model (sustainable environmental building) and SUBETOOL and an analytical hierarchy process (AHP) was used for prioritization. The results of research showed thatthe priority levels for the selected criteria depends to a large extent on the integrated design team which includes customers,architectures, engineers and managers of facilities.

Chen et.al. [9], investigated the sustainable performancecriteria for choosing the construction method in concrete buildings. After reviewing and studying theoretical literature and comparing prebuilt and conventional construction methodsand after surveys among engineers, contractors, manufacturers,etc., a total of 33 sustainable performance criteria were determined. The results of ranking analysis showed that social awareness and environmental concerns were increasingly considered in selecting the construction method. The analysis of the factors of indicators of sustainable performance revealedthat factors can be grouped into seven dimensions; economic factors (long-term costs, ability to build and establish, quality and initial cost), social factors (impact on health and society andimpact on building architecture), environmental factors (environmental impacts).

Falloody et.al [10], in a research studied and examined the use of life cycle evaluation methods to decide on the field of design and sustainability architecture of prebuilt modular buildings. The studied life cycle evaluation was conducted for 5000 prebuilt commercial buildings in San Francisco, California. The results of the research showed that for a modular building with efficient high energy, the priority of design is high and also minimizing the effects of operational energy, since the environmental impacts of the building life cycle is dominant.

Shiaan Lee et.al. [11], in a research identified and examinedthe risk and evaluated modular construction using fuzzy hierarchy analysis process (AHP) and simulation. This researchexamines the management of risks related to modular constructions with a focus on identifying and determining the risk factors and evaluating the effects of identified risk factors on project costs and duration. Risk identification and ranking them by a group consisting of experts and engineers of the modular construction industry were investigated and t distribution and k square distribution were used for analysis. Risk factors and their impact evaluation on the project time andcost were examined and presented in Edmonton, Canada.

Kamali and Hiwaj [12], in research examined and studied theperformance of modular buildings life cycle. Studies have shown that the modular construction method is applicable in various kinds of buildings, including residential, commercial, educational and medical. Environmental performance is one ofthe most important aspects of building sustainability and the main focus of this research is on the environmental dimension.The results of research showed that, on average, modular buildings have better performance than other buildings in providing a better life cycle performance, like building energy performance.

Bafou et.al [13], in a research examined and studied the design and architecture of modular prebuilt buildings withregard to resistance against the earthquake, thermal behavior, energy consumption and life cycle analysis of prebuilt cases. The research findings showed that, on average, greenhouse gasemissions from conventional construction were more than modular construction. Now, considering to the previous researches and their results, the researcher in this paper will study and examine the development of performance criteria (environmental, economic, social) for assessing the sustainability of modular (prebuilt) construction methods versus conventional (construction in site) methods.

RESEARCH METHODOLOGY

The research method in this study is of the mixed type (quantitative and qualitative). In this research, the mixed research method is used to obtain a better understanding of thesubject and to ensure that the problem is addressed in allimportant and effective dimensions. The method of this research is applied in terms of its purpose and the approach of the present research is a descriptive approach, and its method issurvey type. The research methodology in this study includes designing backgrounds, conducting backgrounds, and the methods of analyzing backgrounds.

A. Statistical community of the research

Statistical community of research for obtaining information in the field of identifying and determining the importance of sustainability indicators for choosing a construction method includes main experts of the building, architectures, engineers, contractors, experts, consultants, construction managers, as well as university professors are active in this field and they are considered to answer the questionnaires and informal interviews. These experts, both in prebuilt processes and modular, as well as in conventional construction are active andhave the experience, and also 40 persons were considered.

B. Statistical sample volume

In this research, regarding the fact that the number of people inthe statistical community was determined, the Krejsi and Morgan tables were used to estimate the sample volume. Considering 40 members of the statistical community and usingKrejsi and Morgan table, which is one of the most widely usedmethods for calculating the statistical sample volume, the statistical sample volume was calculated to be 36.

C. Methods and tools for gathering information In this study, in order to gathering information, we used two methods of gathering information including library and field methods using various tools that fit with the subject. In library part, information was obtained by studying various books, valid journals, theses and research treatises, searching on internal andexternal websites, and also examining information in fieldmethod was conducted using questionnaire, consulting with experts and professionals.

The first part of the questionnaire is about the identity information of the respondent, such as job position, work experience, and the nature of organization. The second part contains sustainability performance indicators along a clear description of each index sustainability performance indicator,and respondents were asked to express their point of view by scoring the sustainability performance indicators in comparisonto the sustainability of the prebuilt and conventional construction methods. At the end of the questionnaire, respondents are asked to propose any supplementary criteria notpreviously mentioned in this index of sustainability performance indicators.

D. Validity and **s**ustainability of research questionnaires

The formal and content validity of questionnaire of performance criteria development for assessing the sustainability of the modular construction methods versus conventional methods in previous researches has been examined by the researchers and has been verified by thespecialist and related professors.

Sustainability of the questionnaire or its reliability was calculated using Cronbach's alpha. Usually, the range of Cronbach's alpha reliability coefficient is placed from 0 meansin**s**ustainability, to +1 means complete **s**ustainability, and if theobtained amount is closer to +1, the reliability of questionnaireis greater.

E. Methods and tools for analyzing information

After conducting interviews and receiving distributedquestionnaires among the persons in statistical community, theanalysis of gathered data was performed. To calculateCronbach's alphas and to analyze the descriptive and inferentialstatistics of the research, SPSS software was used. In thisresearch, using Cronbach's alpha method, environmental dimension **s**ustainability 89%, economic dimension **s**ustainability 68%, social dimension **s**ustainability 77%, and total **s**ustainability 91% were obtained. A Likert scale and a 5- point range are used for scoring the importance of sustainabilityperformance indicators. On range scales, the scoring is based on the rank of indicators score and the exact difference betweenthe two points is not clear.

DATA ANALYSIS

A. What are the performance criteria for assessing the sustainability of modular construction methods versus conventional construction?

To investigate and determine the criteria of sustainability performance, two modular and conventional methods, the research findings were evaluated and investigated.

$$H_0=\mu < 3$$
$$H_1=\mu \geq 3$$

Zero hypothesis; the zero hypothesis, which is called the no difference hypothesis, indicates that the difference or statistical relationships which are analyzed, is due to chance or random error. Zero hypothesis is indicated by H_0. This hypothesis, assumes that there is no significant difference or correlation between the studied parameters. This hypothesis is formulated or expressed like a parameter, and its mathematical basis is a breach theorem.

Research hypothesis; the false hypothesis is indicated by H_1 or H_A. This hypothesis is against the zero hypothesis and in many cases, it is matches with the research hypothesis. This means that, it expresses the hypothesis which is against the researcher's expectation through the future results of the research. This hypothesis like zero hypothesis is expressed likea parameter, research hypothesizes are often the investigator's guide in compiling the false hypothesis. In other words, false hypothesis conforms to the research hypothesizes; it means thatthe false hypothesis expresses the investigator's expectation about the results of a research, and this expectation is usually obtained based on the researcher's work experience or experimental evidences. The false hypothesis is the expression,which the researcher wants to research about. Zero and false hypothesizes should be incompatible, it means that they shouldnot interfere in any way.

The single t test is an example of the simplest type of t-tests to determine whether the observed average in sample, which ischosen randomly from the community, has the amount equal tothe assumed average of the community or not.

In quantitative data, to test this hypothesis that whether the average of one sample $\bar{x}$ with the average of community μ, which assumed to have a normal distribution, is the same, use testing the sample t. Use this testing when you want to know whether the estimated average $\bar{x}$ is in line with the average of

In t distributions are similar to the bell-shaped and symmetricnormal distribution, but unlike the normal distribution, theyhave different stretches. If the volume of sample be greater, thedistribution stretch of t will be reduced, and in samples withgreater volume (n <120), the shape of t distribution will bemostly the same with normal distribution. The average of tdistributions is Z=0, like the normal distribution, but theirstandard deviation is more than 1, if the volume of sample begreater, the t standard deviation will approach to 1. Almost thestandard deviation is calculated through the following equation.In t distribution, due to that the standard deviation of community is uncertain, the estimated standard deviation of (S)sample will be applied, and this process of estimating from s,lead to change the t distribution stretch, so that the normalstandard distribution will be used in z test, but one of thedistributions of t relatives, which numbers are variousaccording to the sample's volume, is used in t test. Now, whichone of the t relative distribution in t test should be used specially

in comparing the sample average with community average?

To answer this question, it should be noted that we should consider the freedom degrees in using the t test. In single t test,the freedom degrees are the volume of sample minus 1, it means df = n –1, in the other words, if the sample volume be 10, the freedom degree will be 9. So, among the relatives of t distributions, we will use the distribution which is set by 9 freedom degree.

If the sample volume increases and the degree of freedom move towards infinity, the distribution shape of t becomes closer to the z shape of normal distribution, and finally both distributions t and normal become integrated.

The shape of t distributions is similar to distribution shape ofstandard normal in that both are mono-exponential and symmetric distributions, but the difference is that the t distribution has more stretches and the surface below the end sections is slightly larger than standard normal distribution.

the community (the clear amount $\bar{x}$) or not?

$$t = \frac{\bar{x} - \mu_0}{s/\sqrt{n}}$$

$$\begin{cases} H_0: \mu = \mu_0 \\ H_1: \mu_1 \neq \mu_0 \end{cases}$$

Hypothesis of zero and one are as follows: In this test, the indicator customary to t, which is as follows, is being used. Theresearcher's concern is always about the amount of sample which he has. Usually the t indicator is being used when the amount of samples is lower than 30 and the variance of the community σ^2 is uncertain.

One of this indicator's specifications is its degree of freedomwhich is indicated by n-1. The feature that the t distribution has,is that when the amount of samples is more than 30, it will be match with normal distribution.

$$S_t = \sqrt{\frac{df}{df - 2}}$$

To calculate the single-sample t test, as in calculation of othertests, including what is said for z, the following steps must be followed: The first step is the hypothesis that is supposed to be tested and the opposite hypothesis will be expressed, in the single- sample test the zero hypothesis expresses that the sample average is equal to the average of the community from which the sample is selected. The hypothesis is written in this way:

$$H_0: \mu = \bar{X}$$

The contrary false hypothesis is the difference between the calculated averages of the sample with the related average of the community. This hypothesis can be expressed as directionalor no-direction. The no-direction false hypothesis states that theaverage

of sample differs from the average of desired community, but its direction does not state the difference, but in the directional false hypothesis, the direction of difference between the average of sample and average of the community will be expressed. For example, (it means that the community average is larger than the sample average) or (it means that thecommunity average is smaller than the sample average). For no- direction hypothesis, two-domain test and for directional hypothesis, one-domain test will be used.
Considering that the value of the mean of single-sample t testof the mentioned criteria is 0/001 and smaller than the significance level is 0.05, so the hypothesis will be rejected in this level, it means that there is a significant difference betweenthe obtained average and the normal average, and due to that the value of t statistics and the difference of averages is positive,it means that the obtained average is larger than the normal average, given that the significant of two criteria of greenhousegas emissions and protection of the cultural heritages are morethan 0.05, therefore, these two criteria are not the performancecriteria for assessing the sustainability of modular constructionmethods versus conventional construction. It can be said that the performance criteria, which is listed below, are suitable forassessing the sustainability of modular construction methods versus normal construction (Table 1).
The most important criteria of sustainability of modular andconventional construction are economic dimension, environmental dimension and social dimension. The environmental performance criterion and its sub-criteria, basedon the higher average score, respectively consist of energy performance and effective strategies, renewable energies, consumed energy in total construction process, renewable materials, efficiency strategies of water and sewage, construction materials, location disturbance and appropriate strategies, local materials, selection of location, waste materialsmanagement, alternative transport, and greenhouse gas emissions. The economic performance criterion and its sub- criteria, based on the higher average score, respectively includeoperation costs, construction costs and design, maintenance costs, construction time and design, investments and related risks, final side costs, flexibility, durability and **s**ustainability ofbuilding, and integrated management. Also, the social performance criterion based on the higher average score, respectively include health, resident's health and comfort, useracceptance and satisfaction, performance and usability of physical space, disruption and disturbance of the community, impact on local community development, impact on the local economy, building's aesthetic, safety and security, local accessand amenities, protection of cultural heritages, the health of theworkforce and safety, availability to access the sustainability ofmodular construction methods versus appropriate conventional construction.
The significant value, which is called p-value, and it is shownas spss or sig-value in statistical reports, is a value or criterionwhich is known as significant base and also popular as the firstkind error. This value is considered 5% in human scienceresearches and is determined 1% in medical science. If theresults of examining the difference or relation of the variablesare less than 5%, we say that the possibility of the chance of thisdifference or relationship is very low and it can be concludedthat the difference or desired relationship is significant, and if itis more than 5%, so the possibility of being a chance is a lot andthe relationship or difference of the variables is not meaningful.The results of this research is aligned with the results of Chen et.al. [9], research. They showed in a study that socialawareness and environmental concerns should increasingly betaken into account in choosing the construction method. Theanalysis of factors of the sustainable performance indicatorsrevealed that the factors can be grouped in seven dimensions:economic factors (long-term costs, construction and builtability, initial cost and quality), social factors (impact on thehealth and society, impact on the construction architecture), andenvironmental factors (environmental effects). Also, research findings of Bafou et.al. [13], indicated that in average, thegreenhouse gas emissions of conventional construction weremore than the modular constructions. Therefore, the mostimportant criteria of development performance for assessingand examining the sustainability level of modular constructionversus conventional construction, include dimensions of social, environmental and econ

TABLE 1. STATISTICS OF SINGLE-SAMPLE T TEST FOR EXAMINING THE PERFORMANCE CRITERIA FOR ASSESSING THE SUSTAINABILITY OF MODULAR CONSTRUCTION METHODS VERSUS CONVENTIONAL CONSTRUCTION

Sub-criterion	average	Standard deviation	Difference of average	t statistics	meaningfully
Selection of location	3.69	0.82	0.69	5.07	0.001
Alternative transport	3.56	1.05	0.56	3.16	0.001
Location disruption and appropriate strategies	3.70	0.78	0.70	5.36	0.001
Renewable energies	4.06	0.98	1.06	6.44	0.001
Energy performance and effective strategies	4.07	0.60	1.07	10.80	0.001
Consumed energy in total construction process	3.97	0.81	0.97	7.20	0.001
Effective strategies of water and sewage	3.83	0.86	0.83	5.80	0.001
Local materials	3.69	0.62	0.69	6.68	0.001
Renewable materials	3.89	0.78	0.89	6.80	0.001
Waste material management	3.60	0.67	0.60	5.32	0.001
Greenhouse gas emissions	3.25	1.02	0.25	1.46	0.152
Construction materials	3.75	0.73	0.75	6.15	0.001
Construction time and design	4.04	0.41	1.04	15.06	0.001
Construction costs and design	4.42	0.65	1.42	13.09	0.001
Operation costs	4.44	0.65	1.44	13.09	0.001
Maintenance costs	4.11	0.98	1.11	6.81	0.001
Last side costs	3.97	0.65	0.97	8.92	0.001
Durability and sustainability of building	3.69	0.75	0.69	5.56	0.001
Investments and related risks	4.03	0.91	1.03	6.78	0.001
flexibility	3.83	0.74	0.83	6.79	0.001
Integrated management	3.61	0.84	0.61	4.38	0.001
Residents' health, comfort and rest	4.22	0.80	1.22	9.20	0.001
Impact on the local economic	3.72	0.78	0.72	5.57	0.001
Performance and usability of physical space	3.92	0.69	0.92	7.95	0.001
Aesthetic of building	3.69	0.92	0.69	4.53	0.001
Health of workforce and safety	3.58	1.18	0.58	2.97	0.001
Disturbances in society	3.81	0.71	0.81	6.81	0.001
Impact on the local social development	3.78	0.83	0.78	5.61	0.001
Protection of cultural heritages	3.22	1.05	0.22	1.011	0.316
Access ability	3.42	1.31	0.42	3.02	0.001
Safety and security	3.64	0.96	0.64	3.99	0.001
User's acceptance and satisfaction	4.11	0.82	1.11	8.13	0.001
Local access and amenities	3.58	0.84	0.58	4.16	0.001

B. What are the most important sustainability performance indicators of modular and conventional construction?

Zero hypothesis; the zero hypothesis, which is called the no difference hypothesis, indicates that the difference or statistical relationships which are analyzed, is due to chance or random error. Zero hypothesis is indicated by H0. This hypothesis, assumes that there is no significant difference or correlation between the studied parameters. This hypothesis is formulated or expressed like a parameter, and its mathematical basis is a breach theorem.

Research hypothesis; the false hypothesis is indicated by H1or HA. This hypothesis is against the zero hypothesis and in many cases, it is matches with the research hypothesis. This means that, it expresses the hypothesis which is against the researcher's expectation through the future results of the research. This hypothesis like zero hypothesis is expressed likea parameter, research hypothesizes are often the investigator's guide in compiling the false hypothesis. In other words, false hypothesis conforms to the research hypothesizes; it means thatthe false hypothesis expresses the investigator's expectation about the results of a research, and this expectation is usually obtained based on the researcher's work experience or experimental evidences. The false hypothesis is the expression,which the researcher wants to research about. Zero and false hypothesizes should be incompatible, it means that they shouldnot interfere in any way.

Considering that the value of the mean of single-sample t testof the mentioned criteria is 0/001 and smaller than the significance level is α=0/05, so the hypothesis will be rejected in this level, it means that there is a significant difference between the obtained average and the normal average (amountof test), and due to that the value of t statistics and the differenceof averages is positive, it means that the obtained average is larger than the normal average (amount of test), so it can be saidthat the most important sustainability performance indicators ofmodular and conventional construction are economicdimension, environmental dimension and social dimension,respectively (Table 2). The main reason of this prioritization is that, given that the production of a large part of the modular construction is carried out in the factory; so, it leads to reductionof wasting material as well as industrial production due to the construction and applying the modular members (repetition in using the same parts), leads to cost reduction and improved performance in economic terms.

Falloody et.al [10], in a research studied and examined the use of life cycle evaluation methods to decide on the field of design and sustainability architecture of prebuilt modular buildings. The results of the research showed that for a modularbuilding (prebuilt) with efficient high energy, the priority of design is high and also minimizing the effects of operational energy, since the environmental impacts of the building life cycle is dominant. The findings of this research have relative consistency to the obtained findings of Kamali and Hiwaj [12] research. According to their research results, economic criteriastill play a significant role in distinguishing sustainability in two modular and conventional construction methods. The social dimension has more attention sustainability and importance than the environmental dimension. Also, Taghdiri and Ghanbarzadeh ghomi [14], in their research said that three factors of environmental, construction costs and incentive facilities are essential for using the prebuilding. So, in developing the performance of the sustainability level of modular construction methods versus conventional construction, the economic and financial dimension should be at the center of attention and carefully evaluated and analyzed.

Anindya Nag and Rajarshi Roy [2] dealt mainly with the various graphs used as spanners and also interpreted and reviewed some of the relevant algorithms that are concerned with the Yao graph. They discussed the modifications to these graphs and also explained how this graph could be used to saveenergy and improve performance. The Yao-Yao graph, for example, can be used as a spanner for certain values of the stretch factor. In Yao graph, perpendicular projections are madefrom each node within a sector to the anticlockwise wall and the source node is then connected to its nearest nodes in each cone.

TABLE 2. STATISTICS OF THE SINGLE-SAMPLE T TEST FOR EXAMINING THE MOST IMPORTANT SUSTAINABILITY PERFORMANCE INDICATORS OF MODULAR AND CONVENTIONAL CONSTRUCTION

Sustainability performance indicators	Average	Standard deviation	Difference of average	Statistics of t	Meaningfully
Indicators of environmental dimension	3.78	0.51	0.78	9.10	0.001
Indicators of economic dimension	4.04	0.41	1.04	15.06	0.001
Indicators of social dimension	3.69	0.49	0.49	8.39	0.001

With the help of meaningful tests, we can find out which interpretation is correct. The logic in these tests is simple. If thetwo variables in population do not have difference, how likely is it that our random sample represents the difference between two variables? It is commonly said that where more than five examples of each sample represent a difference that results from a sampling error, the possibility of the sample to be wrong is high. Perhaps our particular example be one of the five examples! As a result, it should be noted that likely the observed difference is due to the sampling error and the hypothesis of thelack of relation in the real population is correct.

C. How to rank and determine the importance of sustainabilityperformance indicators for choosing a construction method?

Inferential analysis of data by Friedman test shows that the importance of sustainability performance indicators for choosing a construction method is different. Because the test meaningful was 0/001 and less than 0/05. According to the obtained results, the ranking and importance of the sustainability performance indicators for choosing a construction method is as follows (Table 3):

D. How is the ranking of environmental, economic, and socialsustainability performance indicators?

Inferential analysis of data by Friedman test shows that the environmental sustainability performance indicators are different. Because the test meaningful was 0/001 and less than 0/05. According to the obtained results, the ranking of environmental sustainability performance indicators is as follows (table 4):

TABLE 3. STATISTICS OF FRIEDMAN TEST FOR RANKING AND DETERMINING THE IMPORTANCE OF SUSTAINABILITY PERFORMANCE INDICATORS FOR CHOOSING A CONSTRUCTION METHOD

Residents' health, comfort, rest	4.22	15.17
Impact on the local economy	3.72	17.82
Performance and usability of physical space	3.92	15.90
Building aesthetic	3.69	16.38
Health of workforce and safety	3.58	16.52
Disturbance in society	3.81	16.86
Impact on the local social development	3.78	15.47
Protection of cultural heritages	3.22	12.79
Access ability	3.42	14.83
Safety and security	3.64	20.33
User's acceptance and satisfaction	4.11	13.81
Local access and amenities	3.58	14.50
Number	36	
Freedom degree	28.80	
k-2 statistics	11	
Meaningfully	0.002	

TABLE 4. STATISTICS OF FREIDMAN TEST FOR RANKING THE ENVIRONMENTAL SUSTAINABILITY PERFORMANCE INDICATORS

Sub-criterion	Account average	Score average
Selection of location	3.69	6.15
Alternative transport	3.56	6.00
Disturbance in location and appropriate strategies	3.70	6.28
Renewable energies	4.06	7.81
Performance of energy and effective strategies	4.07	7.94
Consumed energy in total construction process	3.97	6.94
Effective strategies of water and sewage	3.83	6.81
Local materials	3.69	6.07
Renewable materials	3.89	7.13
Waste material management	3.60	5.83
Greenhouse gas emissions	3.25	4.63
Construction materials	3.75	6.36
Number	36	
Freedom degree	28.80	
k-2 statistics	11	
Meaningfully	0.002	

TABLE 5. STATISTICS OF FREIDMAN TEST FOR RANKING THE ECONOMIC SUSTAINABILITY PERFORMANCE INDICATORS

Sub-criterion	Account average	Score average
Selection of location	3.69	15.51
Alternative transport	3.56	14.82
Disturbance in location and appropriate strategies	3.70	15.43
Renewable energies	4.06	19.51
Energy performance and effective strategies	4.07	19.86
Consumed energy in the total construction process	3.97	17.68
Effective strategies of water and sewage	3.83	17.01
Local materials	3.69	15.21
Renewable materials	3.89	17.81
Waste material management	3.60	14.28
Greenhouse gas emissions	3.25	11.88
Construction materials	3.75	15.61
Construction time and design	4.04	23.74
Construction cost and design	4.42	23.83
Operation costs	4.44	19.86
Maintenance costs	4.11	19.04
Last side costs	3.97	15.79
Durability and sustainability of building	3.69	19.68
Investment and related risks	4.03	16.92
Flexibility	3.83	14.63
Integrated management	3.61	22.63

TABLE 6. STATISTICS OF FREIDMAN TEST FOR RANKING THE SOCIAL SUSTAINABILITY PERFORMANCE INDICATORS

Sub-criterion	Account average	Score average
Construction time and design	4.04	6.17
Construction costs and design	4.42	6.21
Operation costs	4.44	5.36
Maintenance costs	4.11	4.82
Last side costs	3.97	3.90
Durability and sustainability of building	3.69	4.96
Investment and related risks	4.03	4.32
Flexibility	3.83	3.50
Integrated management	3.61	5.76
Number	36	
Freedom degree	8	
k-2 statistics	50.70	
Meaningfully	0.001	

E. How is the ranking of environmental, economic, and social sustainability performance indicators?

Inferential analysis of data by Friedman test shows that the environmental sustainability performance indicators are different. Because the test meaningful was 0/001 and less than 0/05. According to the obtained results, the ranking of environmental sustainability performance indicators is as follows (Table 5):

Inferential analysis of data by Friedman test shows that the social sustainability performance indicators are different. Because the test meaningful was 0/001 and less than 0/05. According to the obtained results, the ranking of social sustainability performance indicators is as follows (Table 6):

I. CONCLUSION

This research was conducted to evaluate and examine the development of performance criteria for assessing the sustainability of modular construction methods versus conventional methods. The most important criteria of sustainability performance of modular and conventional construction are economic, environmental, and social dimensions. According to the research findings and given that the significant level of two criteria of greenhouse gas emissionsand protection of the cultural heritages are more than 0.05, therefore, these two criteria are not the performance criteria for assessing the sustainability of modular construction methods versus conventional construction. The environmental performance criteria and its sub-criteria include location selection, alternative transport, disturbance in location and appropriate strategies, renewable energy, energy efficiency andeffective strategies, energy in the whole process of construction, water and sewage efficiency strategies, local materials, renewable materials, waste materials management, and construction materials. The economic performance criteriaand its sub-criteria include construction cost and design, construction time and design, operating costs, maintenancecosts, final side costs, building **s**ustainability and durability, investments and related risks, flexibility and integratedmanagement. The social performance criteria and its sub- criteria include residents' health, comfort and rest, impact on the local economy, usability of physical space, building aesthetic, health of the workforce and safety, disturbances in the society, the impact on the local social development, access ability, safety and security, user acceptance and satisfaction, and local access and amenities for examining the sustainabilityof modular construction methods versus appropriate conventional construction.

REFERENCES

[1] Stubuti, H., and Ahmadi, J., (1394). Modular and Fictitious Architecture and Mass Production of Housing, Second National Conference on Architecture and Sustainable Urban Landscape, electronically, International Institute of Architecture, Mehrzashhr urbanism.

[2] Kandil, A., El-Rayes, K., El-Anwar, O., (2010). Optimization research: enhancing the robustness of large-scale multiobjective optimization in construction. J. Constr. Eng. Manage. 136 (1), 17– 25.

[3] Kawecki, L.R., (2010). Environmental Performance of Modular Fabrication: Calculating the Carbon Footprint of Energy Used in the Construction of a Modular Home. Ph.D. Thesis. Arizona State University, Phoenix.

[4] Wey, W.M., Wu, K.Y., (2008). Interdependent urban renewal project selection

[5] Reed, R., Bilos, A., Wilkinson, S., Schulte, K., (2009). International comparison of sustainable rating tools. Journal Sustainable Real Estate. 1(1), 1–22.

[6] Erlandsson, M., Borg, M., (2003). Generic LCA-methodology for buildings, constructions and operation services—Today practice and development needs. Build. Environ. 38, 919–938.

[7] Kamali, M. & Hewage, K. (2016), Development of performance criteria for sustainability evaluation of modular versus conventional constructionmethods, Journal of Cleaner Production, PP: 1-35.

[8] ALwaer, H. & Clements-Croome, D.J. (2010). Key performance indicators (KPIs) and priority setting in using the multi-attribute approach for assessing sustainable intelligent buildings, Journal Building and Environment, No 45, PP: 799–807.

[9] Chen, Y. Okudan, G.E. & Riley. D.R. (2010), Sustainable performance criteria for construction method selection in concrete buildings, Journal Automation in Construction, pp: 235–244.

[10] Faludi ,J. Lepech,M.D. & Loisos,G. (2012) Using Life Cycle AssessmentMethods to Guide Architectural Decision-Making for Sustainable Prefabricated

[11] Xian Li, H. Al-Hussein, M. Lei, Z. & Ajweh, Z. (2013), Risk identification and assessment of modular construction utilizing fuzzy analytic hierarchy process (AHP) and simulation, Published by NRC Research Press.

[12] Kamali, M. & Hewage, K. (2016), Life cycle performance of modular buildings:A critical review, Journal Renewable and Sustainable Energy Reviews, No. 62, PP: 1171–1183.

[13] Boafo, F.E. Hee Kim, J. & Kim, J.T. (2016), Performance of Modular Prefabricated Architecture: Case Study-Based Review and Future Pathways, journal sustainability, No. 8, PP: 1-16.

[14] Taghdiri, A, and Qanbarzadeh Qomi, S., (1393). Advantages of pre- fabrication in comparison with conventional construction, Arman Shahr Arc

[15] hitecture and Urban Development Quarterly, No. 15, pp. 15-25.