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Consequences of Design Decisions on Material Waste during Construction Survey of Architects' Point of View, the Case of Jordan

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ABSTRACT

The price of crude oil is ever increasing in Jordan. Energy is the main and most fundamental source for economy and construction industries. Given the fact that material manufacturing and construction in building sector need certain amounts of energy, which is called "embodied energy". The increase of energy prices is reflected on material manufacturing and therefore, any waste means energy waste and more environmental pollution. Construction waste minimization and management are considered as indicators for sustainable construction.

Construction industry is considered as one of the major pillars in the Jordanian economy; consequently, it contributes to a high percent of the national energy bill among many other sectors. This may be considered one of the major reasons to consider the study of building materials in the Jordanian construction sector.

Construction waste increases the cost of building as the energy and natural resources are consumed during manufacturing. The construction industry fundamental aims are to reduce the wastage of construction materials.

This study addresses the incidence of material waste in the Jordanian construction industry and sheds light on decision making during the design phase and its effect on material wastage during construction. This study is intended for the material wastage reduction during construction as a tool to reduce construction costs in Jordan and consequently to reduce the oil bill. At the end, this paper points out the design related major causes of material wastage during construction through a questionnaire designed by the authors.

KEYWORDS: Building materials, Waste reduction, Architect, Contractor, Design decisions, Cost.

INTRODUCTION

Witnessing the massive development in construction, a notion triggers in regard to material wastage. A problem confounding the contribution of many additive costs is found during the establishment phase of building. In contribution not only to society, but to the fact that waste provides more cost, two major issues are highlighted as global crises; energy and natural resources. The construction industry aims always to reduce the wastage of materials all over the world, especially in the developing countries due to strains of limitation in resources.

Many factors affect material waste. Summarized into three main categories, they are as follows:

1. The role of contractors and subcontractors in the site during construction phase. Ling and Toe (2001) mentioned several important reasons to material waste due to contractors, such as proper site storage, proper transportation, material handling, unnecessary cutting, workmen attitudes,

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involvement of subcontractors, proper site accounting and monitoring system and proper site security (Ling and Teo, 2001).

2. The role of design consultants during design and construction phases. Architectural design to buildings may be altered by consultants either from other specialties or from the same field of architecture.
3. The role of client interference during design and construction stages. This could result in many changes that will surely affect the material wastage.

The problem of material wastage during construction has been explored in terms of *in situ* practices in order to have a more comprehensive understanding of this problem. More explorative studies should be implemented in the developing countries (Ling and Teo, 2001).

Locally, no such interest was given to this global trend. Not as pioneers, yet as researchers, the authors have decided to conclude this study to be hopefully a firm base to begin with further exploitation of this frontier. With all factors affecting material waste collected, the authors found it best to manage this study based on three principles: *reduce, reuse and recycle*.

Material wastage can be defined as: "any material, apart from earth materials, which needs to be transported elsewhere from the construction site or used within the construction site itself for the purpose of land filling, incineration, recycling, reusing or composing, other than intended specific purpose of the project due to material damage, excess, non-use, non-compliance with the specifications or being a by-product of the construction purposes" (Ekanayake and Ofori, 2000).

Koskela (1992) defined waste as "any inefficiency that results in the use of equipment, materials, labor or capital in larger quantities than those considered as necessary in the production of a building" (Koskela, 1992; Wooly et al., 2000). The material wastage potentials could be created during the design stage and consequently appear during the construction stage. According to Shen et al. (2004), 1-10% by weight of the purchased construction materials are considered as construction wastes on the construction site (Wooly et al., 2000).

Waste sources during construction may be categorized into: material procurement, material handling, operations, residual related sources and design related ones (Ekanayaki and Ofori, 2004). This research will focus mainly on the effects of design decisions during the design stage on wastage generation during the construction stage. The view will be taken from Jordan as a sampled case study of developing countries. Different views regarding developing countries were found in many other sources and case studies (Zamorano et al., 2008; Papargyropoulou et al., 2011). Research works tackling construction waste management and minimization in developed countries are found in Brebbia (1996).

LITERATURE REVIEW

Interest has been taken by many researchers in the issue of material wastage aiming at reducing environmental impacts due to material wastage and preserving natural resources at the same time. Poon et al. (2004) discussed management issues related to construction waste in public housing projects in Hong Kong. They concluded that waste may be significantly reduced by using pre-casting and system forms. Furthermore, they classified major causes of waste generation to be: improper preparation and handling, misuse and improper processing. According to Poon, appropriate planning is important if the reduction of waste generation is intended (Poon et al., 2004).

In a later article, Poon et al. (2004) discussed the role of material control in waste generation in construction sites with high-rise multi-storey buildings. The researchers explored in detail three issues in this regard: design, material procurement and site management and practices (Poon et al., 2004).

Esin and Cosgun (2007) conducted a survey in Turkey of homeowners in Istanbul to determine the nature and purpose of modifications aiming at providing suggestions to reduce and prevent waste generation. The main purpose of their research work was to identify reasons of waste generation and to come up finally with suggestions for solving related problems (Esin and Cosgun, 2007).

In another study, which was conducted by Pheng and Tan (1997), they detected waste in time in construction projects. They applied a new approach in order to quantify time wastage, where they compared the amount of waste quantifiable under both traditional and new definitions of waste, associated costs and benefits. The study was physically conducted on site, where they collected data with an average interval of three days, and was restricted to projects with JIT (Just in Time) concept (Pheng and Tan, 1997).

In Kuwait, Kartam et al. (2004) focused on recycling efforts leading to the minimization of construction waste. They explored the current waste disposal system and proposed other alternative solutions for proper management and control of construction wastes (Kartam et al., 2004).

One of the main divisions of the Building Research Establishment (BRE) is the Center for Waste and Recycling. Its main interest is to provide the C&D with effective solutions for waste minimization and management. A waste auditing tool called SMARTW (Site Methodology to Audit Reduce and Target Waste) has been developed (McGrath, 2001).

Hsiao et al. (2001) discussed the problem of material waste from the point of view of industrial ecology as it offers a solution for resource recovery from construction wastes. Researchers at the National Taiwan University and Columbia University proposed a study of long-term consequences of utilizing construction waste (Hsiao et al., 2001).

A group-based incentive reward program was proposed by Chen et al. (2002) in order to reduce wastes of construction materials by rewarding workers according to the amounts of construction materials they saved, while they used bar code technique so as to facilitate management of construction materials. Difficulties have been faced during the implementation of the concept on construction sites (Chen and Wong, 2002).

A case study was carried out to analyze the economic feasibility of waste minimization through reusing and recycling of construction waste materials by performing a benefit-cost analysis. It was concluded that waste minimization is economically feasible. Furthermore, the study contributed to the improvement of environmental management (Begum et al., 2012).

It is clear that most of literature reviewed mainly focused on issues far from the role of designers in reducing material waste during the construction phase. The authors propose that the architect as a designer may effectively contribute to reducing material wastes during construction through design decisions made regarding architectural aspects like: dimensions and coordination, material selection and many other variables related to design.

Further scientific work has been implemented in Sri Lanka by Kulatunga et al. (2006), where they investigated the effects of construction work force behaviour on material waste and focused mainly on the attitudes and perceptions of the construction work force involved during construction stages towards minimizing waste. Researchers found that lack of training to reinforce the importance of waste minimization practices obstructed proper waste management in construction industry (Kulatunga et al., 2006).

In another study aimed at providing an analysis of the key issues for an eco-costing of construction waste, a mathematical model was developed for eco-costing wastes from construction site activities based on the sum of multiple variables: cost of waste control, cost saving of recycling and reusing, cost of waste disposal, cost of impact, cost of eco-policy, cost of energy, cost of emissions from equipment and cost related to labour. Researchers were able to quantify the total eco-costs (Yahya and Bousbaine, 2006).

Hao et al. (2008) have used system dynamics modelling to simulate the effect of onsite building material waste sorting. They found that an on-site sorting will reduce dramatically material waste and cost at the same time (Hao et al., 2008).

The authors observed no research conducted in Jordan regarding material waste reduction and the relation it has with design practice as a factor of importance, and to the researchers' knowledge, no studies have been conducted in Jordan regarding other factors that influence material wastes.

Research Objectives

- First, clarifying the cause and effect of the architect's decisions, relatively speaking of the architect's role during planning and design stages, and its effect on the reduction of material wastage, when it comes to real time application through the construction span.
- Second, delivering a note of awareness to the architect about his/her role in material saving to help reduce wastage.
- Third and finally, measuring perception and attitude of architects toward material waste saving.

Research Problem

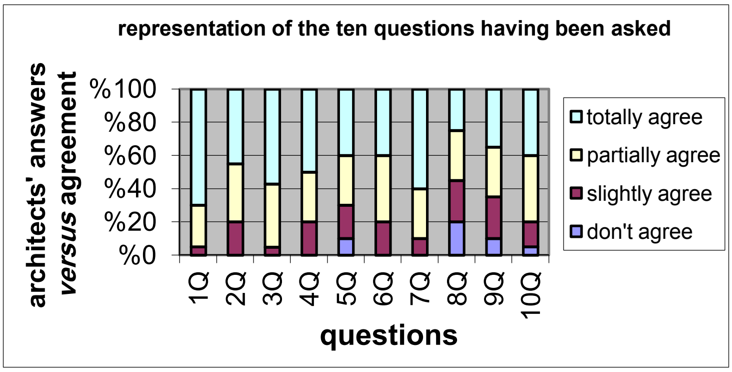
Building materials are viewed as the primary source for building activities, and without them there will be no architecture; as well, they are manufactured utilizing natural resources extracted from the surrounding environment, requiring energy, manpower, technology and water which means, at the end, economical cost. Therefore, any waste in those materials implies waste in human effort and waste in natural resources.

Thus, it is important to understand the nature of material wastage and the causes of such wastage. As there are many reasons for material wastage, this paper will illustrate the consequences of architects' decisions during the design stage on material wastage during the construction phase; being aware of the importance of other factors in reducing material waste in construction projects.

Research Methodology

A fieldwork study was conducted to determine the effects of design decisions (during the design phase) on minimizing material waste generation during construction. Data was collected through a standard questionnaire. The questionnaire was divided into three main parts: the first part contains information necessary for data classification. The second part contains statements regarding factors related to design decisions and their effects on minimizing building material wastage during construction stage. Respondents were asked to indicate the effectiveness of the factors in reducing material wastage on a four-point Likert scale, where 1 represents "totally agree", 2 represents "partially agree", 3 represents "slightly agree" and 4 represents "disagree", as presented in Table 1. The third part of the questionnaire requests respondents to add other design-related parameters that may affect material waste generation in construction sites.

Table 1. Representation of the 10 questions *versus* agreements



The second part of the questionnaire has been designed after the researchers have collected and sorted the main concepts related to the effects of design on waste generation. They are summarized in the following order:

1. The designer who doesn't know the dimensions of materials available in local market.
2. Design modifications and detailing design during construction phase.
3. Designer's inexperience of construction methods and operations' sequences during construction.
4. Designer's lack of knowledge of material alternatives.
5. Material selection made by the designer. The first five questions are analyzed as in Table 2.
6. The interference of the owner during construction.
7. Lack of information in working drawings.
8. Decisions related to dimensions and heights (Dimensional coordination, standardization and modular architecture).
9. Designer's concerns about aesthetics and building's appearance.
10. Designer's awareness of his/her role in either material waste generation or reduction during construction. The second five questions are analyzed as presented in Table 3.

In this study, the targeted participants are practicing architects registered in the Jordan Engineers Association (JEA). A total of about 1061 architectural firms are registered in JEA, where 831 or 78% of architectural firms are located in the capital Amman (JEA, 2007). The reason behind the selection of Amman for this study lies in the fact that it accommodates the largest number of architectural firms. A total of 150 practicing architects were randomly selected for this survey. It is worth saying that this research selected only architects, keeping in mind the important role of other parties, like contractors, civil engineers and different related disciplines in the management and reduction of construction waste. Architects are selected here to investigate their role in waste reduction. The survey was conducted either by personal interviews or *via* e-mail. Thirty one of the questionnaires did not return, seventeen were not readable for data analysis and the rest of 102 questionnaires were ready for analysis.

In this research, which utilizes a survey of public opinion from specialists in the field of architecture, there is a standard procedure followed in administering the questions in numerical order to achieve rational results. The questionnaire took almost four weeks to complete, where two trained researchers, in addition to the authors, helped in distribution and analysis. The survey was conducted during February 2012.

Table 2. One-sample statistics

	Number of Participants	Mean Value	Standard Deviation
Q. 1	102	3.6117	0.6141
Q. 2	102	3.1845	0.8372
Q. 3	102	3.5146	0.6082
Q. 4	102	3.0680	0.7444
Q. 5	102	2.8932	0.9693
Q. 6	102	3.1456	0.7971
Q. 7	102	3.3689	0.8283
Q. 8	102	2.6117	1.1223
Q. 9	102	2.0874	1.0489
Q. 10	102	3.2718	0.8188

Software Package for Social Sciences (SPSS) was used to analyze the data obtained by the questionnaires. One sample T-test was applied to this study to analyze the results of the questionnaires. Results are presented in Tables 4 and 5. The mean and the standard deviation were calculated first as one-sample statistics, and then a one-sample test was tried based on a test value of 2.5, which should construct the medium of our four-point Likert Scale. Tables 6, 7 and 8 are about factor analysis of communalities, total variance and component matrix that aim to group questions to obtain further simple results.

Table 3. One-sample test for the variables studied

Test Value = 2.5						
95% Confidence Interval of the Difference		Mean Difference	Sig. (2-tailed)	df	t	
Upper	Lower					
1.2524	1.0002	1.12626	0.000	98	17.725	Question 1
0.7523	0.4313	0.59184	0.000	97	7.318	Question 2
1.1058	0.8534	0.97959	0.000	97	15.401	Question 3
0.6989	0.4032	0.55102	0.000	97	7.397	Question 4
0.5741	0.2014	0.38776	0.000	97	4.131	Question 5
0.7270	0.3761	0.55155	0.000	96	6.240	Question 6
1.0471	0.7157	0.88144	0.000	96	10.559	Question 7
0.3264	-0.1305	0.09794	0.397	96	.851	Question 8
-0.2258	-0.6299	-0.42784	0.000	96	-4.203	Question9
0.9037	0.5706	0.73711	0.000	96	8.786	Question 10

Table 4. Factor analysis communalities

	Initial	Extraction
Q. 1	1.000	0.622
Q. 2	1.000	0.684
Q. 3	1.000	0.788
Q. 4	1.000	0.584
Q. 5	1.000	0.540
Q. 6	1.000	0.467
Q. 7	1.000	0.739
Q. 8	1.000	0.547
Q. 9	1.000	0.741
Q. 10	1.000	0.626

Table 5. Total variance explained. Extraction method: principal component analysis

Component	Initial Eigen values			Extraction sums of squared loadings			Rotation sums of squared loadings		
	total	% of variance	Cumulative %	total	% of variance	Cumulative %	total	% of variance	Cumulative %
1	1.623	16.227	16.227	1.623	16.227	16.227	1.510	15.096	15.096
2	1.331	13.310	29.536	1.331	13.310	29.536	1.297	12.973	28.069
3	1.239	12.390	41.926	1.239	12.390	41.926	1.209	12.092	40.161
4	1.126	11.262	53.188	1.126	11.262	53.188	1.177	11.768	51.929
5	1.019	10.193	63.381	1.019	10.193	63.381	1.145	11.452	63.381
6	0.874	8.736	72.117	-	-	-	-	-	-
7	0.852	8.518	80.635	-	-	-	-	-	-
8	0.815	8.154	88.789	-	-	-	-	-	-
9	0.641	6.409	95.198	-	-	-	-	-	-
10	0.480	4.802	100.00	-	-	-	-	-	-

Table 6. Component matrix. Extraction method: principal component analysis, 5 components extracted

	Component				
	1	2	3	4	5
Q. 1	-	-	-0.417	0.611	-
Q. 2	-	0.753	-	-	-
Q. 3	-	-0.307	0.487	0.514	0.368
Q. 4	0.373	-	0.548	-	-
Q. 5	0.656	-	-	-	-
Q. 6	-	-	-0.555	-	-
Q. 7	-	-0.511	-	-	0.637
Q. 8	0.642	-	-	-	-
Q. 9	0.496	0.463	-0.360	-	0.388
Q. 10	0.479	-	-	-0.576	-

DISCUSSION

After analyzing the questionnaire, the first category which is about "totally agree" presents the largest percentage as shown in Table 1. The answers vary from 70% for question number 1, which is about the designer's knowledge of available materials in the local market, to 11% for question number 9, which is about aesthetics and building's appearance. For questions 3 and 7, which are about the architect's inexperience in construction methods and operation sequence during construction and about lack of information in working drawings, the percentages are higher than 50%. For the rest of questions 2, 4, 6, 8 and 10, which are about design modifications during construction, designer's lack of knowledge of material alternatives, interference of the owner during construction, decisions related to dimensions and heights and the designer's awareness of his/her role in waste generation during construction, the percentages are less than 50%.

The second category, which is about "partially agree", presents the second largest percentage as shown in Table 1. The answers vary from 52% for question number 4 to 26% for question number 1. The percentages for all questions are close to each other. Different from the first category which contains a wider range, the third category, which is about "slightly agree", presents the third largest percentage as shown in Table 1. The answers vary from 23% for the 9th question to 6% for the 3rd question. The percentages for all questions are close to each other. The fourth category, which is about "disagree", presents the fourth largest percentage as shown in Table 1. The answers vary from 41% for the 9th question to 0% for the 1st and 3rd questions.

Table 2 analyzes each question from 1st to 5th. The highest difference is in question number 1, where the percentage varies from 0% to 70%. The lowest difference is in question number 5, where the percentage varies from 11% to 32%. Question number 5, which is about the selection of materials by the designer, is slightly affecting the material wastage according to the respondents' answers. It is mainly the architect who doesn't know the dimensions of the materials available in local market which causes the greatest effect on material wastage. Question number 3 also has a wide range between the highest and lowest percentages. The range varies from 59% to 0%. It is considered the second important issue after the first question. After looking at Table 3, question number 7 comes in the third place in importance as the variation between the highest and lowest percentages ripples from 58% to 3%. Question number 9 has an inverted result compared to the first category "totally agree", coming last with 11% only. The fourth category "disagree" comes first with 41%. This is in line with our questionnaire, as most architects do not think that the building's appearance or style affects material wastage. Question number 8 has an almost horizontal linear form. Local architects do not think that modular architecture or standardization of used materials helps in reducing material wastage. This result seems to be a little bit strange, but the main reason is that Jordan has no companies that produce modular constructions like beams, curtain facades and other construction parts.

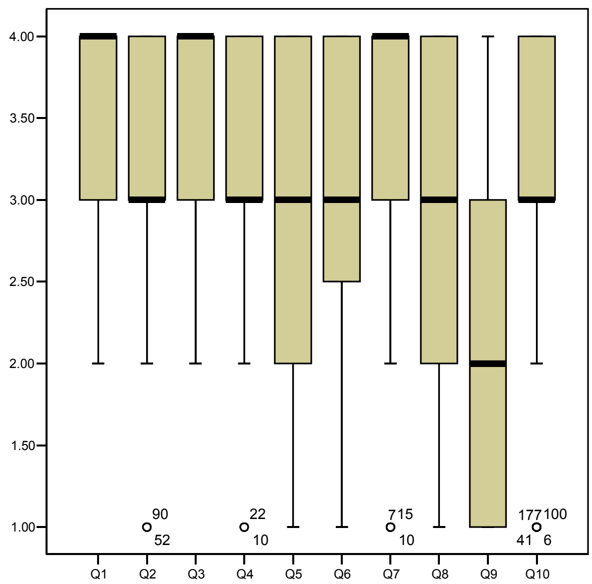


Figure (1): Box plot representing the ten questions showing the distribution of answers around their medians.Whiskers are also shown in the chart with extreme values

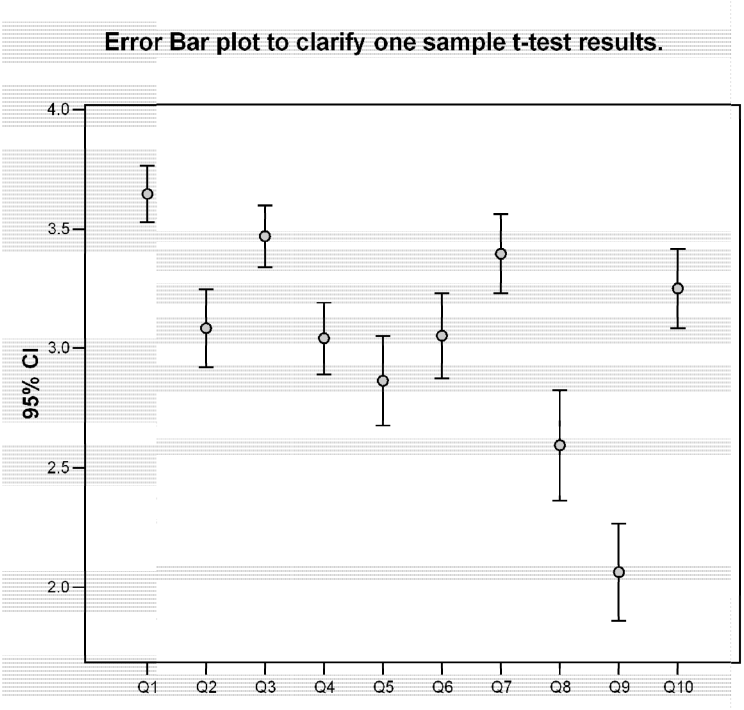


Figure (2): Error bar chart to clarify statistical test results

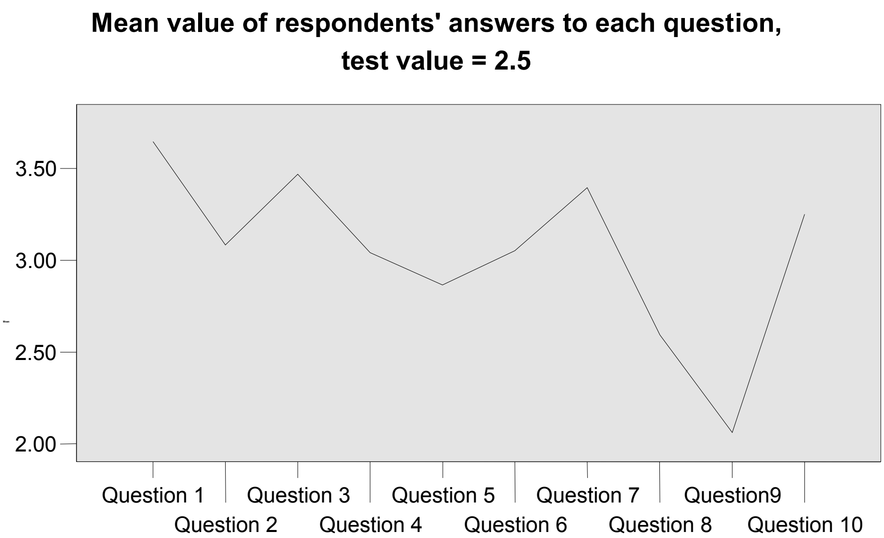


Figure (3): Line chart showing how much answers are far from the test value of 2.5

The second part of the questionnaire that contains further statements, suggested by the participating architects, is of great importance. The factors that were mentioned by the participating architects are related to design decisions and their effects on creating or minimizing buildings' material wastage during the construction phase. They added several factors such as un-specified budget, inaccurate calculation of required materials, unskillful or inadequate experience of the practicing architect, among others. These factors might be separately investigated in another study.

From Figure 1, it is obvious that architect do not agree that architects' concerns about facade aesthetics do really affect material wastage which is presented by question number 9, their attitudes and points of view disagree with the statement about the effects of aesthetics. The same thing applies also for question 8, but to a lesser degree. This appears clear in Table 3 used to find any differences between the test value and the means of respondents, where there was a difference between the test value and the answers which is much lower than the given value, t was 0.851 which has a statistical significance on a level lower than 0.05. For questions 5 and 8, there was a large scatter in answers which reflects a wide range of attitudes towards the effects of the selection of low quality building materials on material wastage; the same thing applies to question 9 which is a statement on concerns about aesthetics in design and the effects of aesthetics on material wastage.

For questions 5 and 8, architects' answers are largely scattered between two distant values. This indicates that there is a large number of architects who do not agree with the statement. For questions 2, 7 and 10, there are some extreme answers toward disagreement that are statistically neglected, simply because they do not lie within the quartiles represented.

Figure 3 shows how answers are far from the mean of the measuring scale represented in the test value, which is 2.5. One can observe how questions 8 and 9 are lower than the test value, which indicates the disagreement of architects with the statement being questioned.

RESULTS AND CONCLUSIONS

After applying the T-test to the group of questions, a number of findings were reached. In Table 4, where one-sample statistics is applied, questions 8 and 9 appear with no significance in our study. The mean values for those two questions are 2.6117 and 2.0874, respectively, and their standard deviations are 1.1223 and 1.0489, respectively. Decisions related to dimensions and heights, or in other words the dimensional coordination, standardization and modular architecture, in addition to the designer's concerns in aesthetics and building's appearance seem to be irrelevant or not affecting this study.

They might be of importance, but not upon wastage during construction. Table 5 emphasizes this, where the values of "T" for those two questions are 1.010 and -3.993, respectively. The mean differences are 0.1117 and -0.4126, respectively.

In order to be more specific, a factor analysis is performed as in Table 6. The communalities are first found, then the total variance is explained in Table 7. The component matrix is calculated based on the extraction method of principal component analysis. Questions 1 and 3 can be grouped together.

The designer knowledge in the dimension of materials which are available in the local market and the designer's inexperience in construction methods and operations' sequence during construction, seem to be related to each other. Questions 2 and 9 can be grouped together. The design modifications and detailing design during the construction phase and the designer's concerns in aesthetics and building's appearance can be related to each other if we do not want to omit question 9.

Questions 4 and 6 can be also grouped together. The designer's lack of knowledge of material alternatives and the interference of the owner during construction can be of great impact upon material wastage during construction. Questions 5, 8 and 10 can be grouped together. Material selection achieved by the designer, decisions related to dimensions and heights and the designer's awareness of his/her role in waste generation during construction are of great importance upon material wastage during construction.

This study is set to realize the effect of many variables on material wastage during the construction stage. There are many variables which influence material wastage during construction, like construction methods, building material selection, site management, cost, preferred quality in finishing and many other variables; all the mentioned variables influence construction waste generation on site, but this work is only restricted to the study and analysis of the designers' decisions during the design stage, as one of the many other variables which influence construction waste generation. Authors are aware of the importance and effect of other variables, and they might be studied in future work.

The survey demonstrates practical issues reflecting more redundant waste. The random sample of people who answered the questionnaire was mostly practicing architects who pointed out important factors due to their sufficient experience in the field. They also mentioned more causal matters to excess waste found locally in Jordan in general and Amman in particular. This relevantly explains the crises of energy consumption and depleting limited resources in such developing countries with low resources.

This problem concerning wastage of materials has already shown its serious effect on oil prices globally. Rising cost of energy, the unwise consumption and wastage of materials concluded the total bill for oil in Jordan to exceed half of its budget. This led the authors to start a study highlighting guidelines in regard to materials and limitation of resources problem, which may establish a firm notion to encourage further detailed studies about: reduce, reuse and recycle, which are unfortunately absent in Jordan.

RECOMMENDATIONS

The final output of this study may put forward a set of recommendations regarding the issue of material wastage. It is apparent that the role of the architect is very important. There should be some sort of effort to remind architects about their role in this regard. Design decisions during the early design phase are very important to establish material waste reduction policies even during the construction phase.

In Jordan, further work is needed to be conducted in order to understand the role of other parties in the building sector, an important issue that should be discussed.

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