IDENTIFYING SOURCES OF DESIGN ERROR IN THE DESIGN OF RESIDENTIAL BUILDINGS

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ABSTRACT

There is scarce literature discussing errors as a source of waste in design. Also, there is poor understanding on what constitutes waste in the context of design development. This paper aim is to identify the main perceived causes of errors and waste in the design phase of residential buildings. The paper reports on part of an on-going PhD research, which aims to develop a framework to support designers to identify sources of errors and reduce waste through different design phases. In order to obtain an initial understanding of the designers' perception of waste and gauge their knowledge of design errors, interviews were conducted in Jordan, with senior design engineers from the private sector, lead design engineers from the Jordan Engineers Association, and the assistant to the manager of Public Works. Results demonstrate perceptions that the main causes of errors and waste are related to (a) client changes; (b) design drawing and detail issues; and (c) problems with following regulations and building codes.

KEYWORDS

Building Design, Design error, Waste, Non-value adding.

INTRODUCTION

The architect is typically responsible to develop the design concept from inception to the completion of construction. Therefore, the architect's play an important role because any deficiencies in the inception phase may lead to successive deviations in the construction phase (Oyedele and Tham, 2007). There is a consensus in the literature that the architect role is crucial in minimising, and "designing out waste" (Oyedele and Tham 2007, Osmani et al. 2007).

Designers will develop a design solution based on the approved project requirements and constraints as outlined in the client's brief. It is the client's right to pursue the designers to fix errors that were identified in the design documents. However, there will be a notable cost increase to address these changes at later design stages.

This research attempts to identify the perceived causes of errors in the design phase that result in waste. The research focused on the architect due to his/her involvement from the initial stages of the project.

Studies such as Innes (2004); cited in Osmani et al. (2006, 2008) reported that the architect is responsible for about 33% of waste generation due to design errors. Burati et al. (1992) reports that about 60% of project construction deviations are as result of

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design errors, which is in agreement with findings from other studies (Ransom 1987, and Kirby et al. 1988).

It is well known that the costs of correcting errors in early design stages is considerably smaller compared to the cost of correcting the same errors during the construction phase. The McLeamy curve shows that design changes increase the project cost across as all phases of the project. Lam (1994) discussed that the majority of errors are originated at the initial stages and related to the poor knowledge of or lack of application of building codes. Rounce (1998) identified reasons for errors in design as lack of coordination, adding missing information, and misinterpretation of design standards. Furthermore, Rounce (1998) also discussed that the architectural quality of the design and management practices are potential sources of negative impact on projects.

This research attempts to identify the perceived causes of errors in the design phase of residential buildings that result in waste. The research focused on the architect due to his/her involvement from the initial stages of the project. The reason for selecting the stage is that many of the project deficiencies could be avoided in design, which will eliminate waste, and help control project cost and project schedule overrun.

ERROR IN DESIGN

Error has been defined in different ways in the literature. Stewart (1992) defined human error as "an event or process that departs from commonly accepted competent professional practice; it excludes such unforeseen events." For the purpose of this research, Stewart definition of error was adopted.

The design process needs to be organised efficiently to minimise the effects of complexity and uncertainty (Formoso et al 1998). Poor design planning may result in incomplete information to undertake design tasks, and lead to discrepancies in construction documents (Tzortzopoulos and Formoso 1999).

Problems in design management, which may lead to errors or omissions, have been described in the literature. Several studies have pointed out that poor design has a strong impact on the level of effectiveness during the production stage (Ferguson 1989). A large percentage of defects in buildings arise through decisions or actions taken during the design stages (Cornick 1991). Lack of communication, insufficient documentation, missing input information, lack of coordination between disciplines are main problems in design management (Cornick 1991, Koskela et al. 1997). Coles (1990) reported that the most significant causes of design problems are poor briefing and communication. Common concerns included late approvals from clients and insufficient time for completion of design documents.

Consequently, there is a clear relationship between errors and waste, e.g. if the design documents include many errors then the potential of waste generation throughout the process is high. Errors in design have negative impact on the design phase itself and also on the construction phase. More importantly, these might negatively impact the post construction/use phase of a building, with vast negative consequences for the clients.

WASTE IN DESIGN

It is acknowledge in the literature that errors are main contributor of waste. To eliminate waste in both design and construction we should control and eliminate errors first. A design free of errors is more likely to produce project free of waste.

The term waste does not give an accurate description of the cost reduction potential (Forsberg and Saukkoriipi 2007). Waste defined by Womack and Jones (1996) as "any activity, which absorbs resources but creates no value". The term 'waste' is often used synonymously with the term 'non-value adding costs' (e.g. Buzby, et al, 2002).

Complexity in design causes iteration which can be value-adding or wasteful. Wasteful iterations, called rework, may stem from inefficient information flow in design (Hickethier et al 2012). Formoso et al (1999) defined non-value adding costs as "any losses produced by activities that generate direct or indirect costs but do not add any value to the product from the point of view of the client".

Waste associated with building design is one of the causes of the high cost and slow progress of construction projects. Proper management of waste at the design stage is therefore a fundamental step towards achieving speedy delivery of building projects at minimum cost (Zoya Kpamma and Adjei-Kumi 2011).

According to Undurraga (1996) about 20-25% of total construction time is wasted as a result of design deficiencies. Waste in design arises out of delays, waiting, design errors, over processing and negative iteration (Ballard, 2000). The waste resulting of these sources in the design process can have major impacts by undermining efforts to complete construction products on time.

Huovila et al. (1997) highlights activities to help eliminate waste in the design process: e.g. reduce uncertainty, which causes of rework, especially in the early stages of design; reduce waiting time, and also allow the transfer of information to be made in smaller batches. Forsberg and Saukkoriipi (2007) suggest two different ways of reducing the production cost, either by increasing productivity or reducing waste.

The measurement of waste have mainly been limited to production at site and emphasis on activities in terms of value and non-value adding when trying to achieve cost reductions (Forsberg and Saukkoriipi 2007). However, design errors are major contributors to change orders and rework, which in turn result in a high volume of construction waste (Nagapan et al 2012).

Therefore, elimination of waste in both design and construction requires an emphasis on controlling and eliminating errors in design, as errors are main contributors of waste and value loss.

RESEARCH METHOD

The interview approach is one of the primary sources of qualitative data collection (Skearan and Bougie, 2010). Yin (1999) listed six methods of data collection i.e.: interviews, documents analysis, archival reviews, participants' observation, observations, and physical artefacts. In the context of this research, interviews have been adopted to explore existing perceptions in more depth about the causes of errors occurred in the design phases.

The interview is considered a suitable process of data collection that is capable to provide rich information (Silverman 2006). This research used unstructured, open-ended face-to-face interviews to stimulate discussion and break down any barriers between the interviewer and interviewees. The interview was conducted with 10 people from private consulting firms, Jordan Engineers Association (JEA) and Public Works. The interviews were conducted with lead designers with more than ten years of experience in design and review of design documents from three engineering sectors. The duration of each interview was about 30-45 minutes.

Interviews started with the question: What are the causes of errors in the various design phases and can you identify errors and their types? The reasons for asking this broad and open-ended question is to solicit as much information as possible and to allow the participants share their unbiased and unobstructed opinions with the researcher.

The results were validated with a follow up interview and the validated data was used to create a questionnaire to be tested against five-point Likert scale. The questions for each error category were distributed to the original population to get their responses. Based on the findings of the interviews, a list of error categories were identified and questions for each category were formulated. The error categories identified are considered to be those that have the highest potential to cause various types of waste.

RESULTS

The collected data was analyzed and the results are presented in Tables 1-4. Column 8 (C8) in these tables is a calculated weighted average based on the Likert Scale. The weighted averages are then used to calculate the weighted average percentage as can be seen in column 9 (C9) in Tables 1-4.

CATEGORY OF ERRORS ATTRIBUTED TO THE CLIENT

Based on the interviews, the types of errors attributed to the client that have high potential for producing waste are presented in Table 1, Column 8 (C8). The results showed that the respondents gave all the questions in each sub-category similar weighted average values that ranged between 2.47 to 3.27 based on 5-point Likert Scale. The data also showed that the 57% of the ten respondents replied with strongly agree, and 31% of the respondents replied with agree with the error causation attributed to client. It is apparent that the majority (88%) of the respondents believe that client interventions are a major source of design errors, with high potential of waste generation. Question 1-5 in column 1 of Table 1 (i.e. client briefing), and Questions 6-8 (i.e. budget and financing) have the height two ranks in the potential of waste generation, respectively.

Table 1: Errors attributed to client intervention

C1	C2: Error Category Attributed to Client	C3	C4	C5	C6	C7	C8	C9
Q1	Errors due to inexperience of the client about construction	6	4	0	0	0	3.07	8.27
Q2	Errors due to ambiguity in describing the project aim and objectives	4	4	0	1	1	2.60	7.01
Q3	Errors due to the client not providing his requirement in written form	6	3	1	0	0	3.00	8.09
Q4	Errors due to uncertainty to allocate the space and capacity	4	3	0	2	1	2.47	6.65
Q5	Errors due to the client rarely provide sketch about the potential design	5	3	0	0	2	2.60	7.01
Q6	Errors due to client hiding financing route or overestimate budget value	4	3	0	2	1	2.47	6.65
Q7	Errors due to amount (budget) for the design and construction is not available in hand.	7	3	0	0	0	3.13	8.45
Q8	Errors due to client requirements exceed the potential budget	6	4	0	0	0	3.07	8.27
Q9	Errors due to client delay to advice to proceed after meeting the requirement	4	4	0	2	0	2.67	7.19
Q10	Errors due to disruption and lack of commitment of fees payment	8	2	0	0	0	3.20	8.63
Q11	Errors due to client selecting different finishing materials than the one specified	9	1	0	0	0	3.27	8.81
Q12	Errors due to budget and the plot size do not fulfil the client requirements	5	2	0	1	2	2.47	6.65
Q13	Errors due to client did not consider the timelines for design process and the construction completion	6	4	0	0	0	3.07	8.27
	Sum						37.07	100

[3]Tables' (1-4) keywords

CATEGORY OF ERRORS ATTRIBUTED TO FAILURE TO IMPLEMENT REGULATIONS AND BUILDING CODES

The interviews revealed this category of error and a list of questions presented in Table 2. The study respondents identified only three causes of errors due to the failure to implement regulations and building codes. This is only about 30% of the list of error causation identified under sources of errors attributed to building code. This makes sense because the engineering codes in Jordan focuses on the shape and form of the structure relative to the plot and of the total coverage area according to the classification of the plot type (class A, B, C and D). Questions 1 through 3 have the same potential of waste generation on the design side but have bigger implications of waste generation on the construction side.

[3] Tables' (1-4) keywords: C1 Question No/ C2 Interview data/ C3 Strongly agree/ C4 Agree/ C5 Neither agree nor disagree/ C6 Disagree/ C7 Strongly disagree/ C8 Weight average/ C9 Weight average percentage

Table 2: Error sources attributed to failure to implement regulation and codes

C1	C2:Errors Attributed to Failure to Implement Regulation and Building Codes	C3	C4	C5	C6	C7	C8	C9
Q1	Errors in calculating the vertical dimensions of the building	5	4	0	1	0	2.87	31.85
Q2	Errors due to violation in clearance between adjacent buildings	6	3	0	1	0	2.93	32.59
Q3	Errors due to identifying the plot correct dimensions and boundaries	8	2	0	0	0	3.20	35.56
						Sum	9.00	100

ERRORS ATTRIBUTED TO FAILURE TO ADHERE TO SPECIFICATIONS OF INSULATION MATERIALS AND/OR POOR MATERIAL SELECTION

The data analysis of the questions under this section showed that a low percentage of the respondents think that this category of error is important in terms of generating waste. Consequently, this category of error is not further discussed for the purposes of this paper.

CATEGORY OF ERRORS ATTRIBUTED TO LACK OF DETAILS IN DRAWINGS AND/OR MISS-INTERPRETATION OF DRAWINGS

The interview revealed thirteen potential causes of errors under this category (see Table 4). The data analysis of the weighted average and weight average percentages are presented in Table 4 Columns 8 and 9. The data showed that 77% of the respondents answered with either strongly agree or agree to the questions listed in Table 4 Column 2. The data showed that this error causation is high priority to the respondents with the highest potential for waste generation in the input stage.

Table 3: Error sources attributed to lack of details of drawing

C1	C2: Errors Attributed to Lack of Details of Drawing	C3	C4	C5	C6	C7	C8	C9
Q1	Errors in linking the street level with building level	2	2	0	4	2	1.87	5.89
Q2	Errors in identifying the ground floor level	5	3	0	1	1	2.67	8.42
Q3	Errors in linking stair case with the floor level	3	2	0	3	2	2.07	6.53
Q4	Errors due to using existing design and specifications of other projects	8	2	0	0	0	3.20	10.11
Q5	Errors in architectural details due to using details from other projects	7	2	0	1	0	3.00	9.47
Q6	Errors due to insufficient internal details (i.e. furniture layout) on the architectural drawings, which results inappropriate allocation of electrical works and outlets	4	4	0	2	0	2.67	8.42
Q7	Errors due to orientation and direction specially of kitchen and bathrooms	3	2	0	1	4	1.93	6.11
Q8	Errors due to using different sets of drawings; one of permitting and one for construction	5	3	0	1	1	2.67	8.42
Q9	Errors due to changes of architects working on the project due to either leaving the company or taking vacation	5	4	0	1	0	2.87	9.05
Q10	Errors due to client selecting material without consulting with Architect	7	3	0	0	0	3.13	9.89
Q11	Errors due to misinterpreting or ignoring building code	5	4	0	1	0	2.87	9.05
Q12	Errors due to missing or lack of details and specifications for steel, wood and aluminium work	5	3	0	2	0	2.73	8.63
						Sum	31.67	100

DISCUSSION AND CONCLUSIONS

There is a clear relationship between errors and waste. Errors in design documents have a negative impact on design phase and in construction phase and might affect the post construction phase, depending on the type of errors and time of detection the errors.

The results of the interviews identified four error categories in the residential buildings in Jordan. Client briefing, financing, drawings, and building codes were the subcategories identified with the highest potential for waste generation, according to interviewees perception.

The analysed data showed that error causation attributed to client interventions and to design/engineering drawings had overall weighted average percentage of 45.80% and 39.13%, respectively. Therefore, this reveals that the interviewees perceive these to be the sources of errors with the highest waste generation potential. The errors attributed to regulations and building codes was 11.12 %. Therefore, these categories of errors will be further investigated in the continuation of this PhD research. It is interesting to note that highly qualified professionals, as those involved in this research, believe that most of the design errors are caused by factors which are outside their direct control, i.e. client changes, with very little consideration to any factors which are within the control of design teams, like more appropriate planning practices and the use of technology to support design development. This reveals a possible bias on the interviewees perceptions, and a need to further investigate the real sources of design errors as they occur on projects. There is also a need to further understand the concept of design error itself, especially in early design, and on how to differentiate between design changes which add to value creation (and are a natural part of design development) from those which are non value adding and generated due to lack of appropriate information and poor information flows, for instance.

A further result from this study is that the engineering community in Jordan does not recognize lean construction principles, and are less aware of the potential of waste reduction.

Research limitations: the interview excluded contractors and users due to time and cost limitations. Lastly, during the questions process additional errors emerged e.g. (Errors and omissions in the bills of quantities; Details needed; Do not conform to drafting standards; Errors in symbols and abbreviations) which were not included in the study evaluation and analysis. These will be included in the later stages of the research.

REFERENCES

Ballard, G, (2000). “Positive vs negative iteration in design”. Proceeding of IGLC 8 Brighton, UK.

Ballard, G. and Koskela L. (1998). “On the agenda of design management.” Proceedings of IGLC-6, Guaruja, Brazil.

Burati, J.L., Farrington, J.J. and Ledbetter, W.B. (1992). “Causes of quality deviations in design and construction.” Journal of Construction Engineering and Management, 118(1) 34-46.

Buzby, C. M., Gerstenfeld, A., Voss, L. E., and Zeng, A. Z. (2002). “Using lean principles to streamline the quotation process: a case study” Industrial Management & Data Systems, 102 (9) 513-520.

Chow, L.K. and Ng, S.T., (2007). “Expectation of performance levels pertinent to consultant performance evaluation”. International Journal of Project Management, 25(1) 90-103.

Coles, E.J. (1990). “Design Management: A study of practice in the building industry” The Chartered Institute of Building, Occasional Paper No. 40, 32 pp.

Cooper R. and Press, M. (1997). “The Design Agenda: A Guide to Successful Design Management” John Wiley & Sons, London. 298 pp.

Cornick, T. (1991). “Quality Management for Building Design”. Rushden, Butterworth, 218 pp.

Cross, N. (1994). “Engineering Design Methods. Strategies for Product Design” London, Wiley, 2nd ed., 179 pp.

E. Zoya Kpamma and T. Adjei-Kumi (2011). “Management of Waste in the Building Design Process: The Ghanaian Consultants' Perspective” Architectural Engineering and Design Management (7) 102-112.

Ferguson, I. (1989). “Buildability in Practice”. London, Mitchell. 175 pp.

Formoso, C. T., Isatto, E. L., and Hirota, E. H. (1999). “Method for waste control in the Building Industry” Proceeding of IGLC 7 Berkeley, USA.

Formoso, C., Tzortzopoulos, P. Jobim, M., and Liedtke, R. (1998). “Developing a protocol for managing the design process in the building industry.” Proceedings of IGLC-6, Guaruja, Brazil.

Forsberg, A. and Saukkoriipi, L (2007). “Measurement Of Waste and Productivity In Relation To Lean Thinking” Proceedings IGLC-15, Michigan, USA.

Gernot Hickethier, Iris D. Tommelein, and Fritz Gehbauer (2012). “Reducing Rework in Design by Comparing Structural Complexity Using a Multi Domain Matrix” Proceedings of IGLC-20, Singapore.

Han, S., Love, P. and Feniosky Peña-M., (2011). “A system dynamics model for assessing the impacts of design errors in construction projects.” Mathematical and Computer Modelling. Available online 22 June 2011, ISSN 0895-7177

Hollnagel, E., (1993). “Human reliability analysis: Context and control”. London, Academic Press.

Huovila. P. Koskela. L. and Lautanala. M. (1997). “Fast or concurrent: the art of getting construction improved” in: L.F, Alarcon (ed) Lean Construction, A,A. Salkema. Rotterdam. 143-160.

Innes, S., (2004). “Developing tools for designing out waste pre-site and on-site.” Proceedings of Minimising Construction Waste Conference: Developing Resource Efficiency and Waste Minimisation in Design and Construction, New Civil Engineer, London, United Kingdom.

Kirby, J.G., Furry, D.A. and Hiks, D.K. (1988). “Improvements in design review management.” Journal of Construction Engineering and Mgmt, 114(1) 69-82.

Koskela, L, and Huovila, P “(1997). “On foundations of concurrent engineering”, in: C, Anumba and N, Evbuomwan (eds). Concurrent Engineering in Construction CEC97,3-4 July, The Institution of Structural Engineers, London, 22-32.

Koskela, L. (1992). “Application of the New Production philosophy to Construction” Technical Report No. 72, Stanford, CIFE, Stanford University.

Lam Siew Wah, L.C.M.T.W.A., ISO 9000 in Construction1994, PTSL,UKM: McGraw Hill Book Co.

Love P., Mandal, P. and Li H., (1999). “Determining the casual nature of rework in construction projects.” Construction Management and Economics, 17(4) 505-515.

Love, P., Smith, J., and Han, S., (2011). “Sense making of rework causation in offshore structures: People, organization and project” COBRA 2011. RICS Construction and Property Conference. University of Salford, United Kingdom.

McLeamy, P. (2004). "Integrated Project Delivery: McLeamy Curve http://www.msa-ipd.com/MacleamyCurve.pdf.

Osmani, M., glass, J. and price, A., (2006). "Architect and contractor attitudes to waste minimization." Proceedings of the Institution of Civil Engineers, Waste and Resource Management, 159, 65–72.

Osmani, M., Glass, J., Price, A.D.F., (2008). "Architects' perspectives on construction waste reduction by design" Waste Management 28 (7) 1147–1158.

Oyedele, O.L., Tham, K.W. (2007). "Clients' assessment of architects' performance in building delivery process: Evidence from Nigeria." Building and Environment 42, 2090–2099.

Ransom, W.H. (1987). "Building Failures: Diagnosis and Avoidance" E. & F. N. Spon, London.

Rounce, G. (1998). "Quality, waste and cost considerations in architectural building design management." International Journal of Project Mgmt. 16 (2) 123-127.

Sasitharan Nagapan, Ismail Abdul Rahman , Ade Asmi, Aftab Hameed Memon, Rosli Mohammad Zin (2002). "Identifying Causes of Construction Waste - Case of Central Region of Peninsula Malaysia" International Journal of Integrated Engineering, 4.(2) 22-28.

Sekaran,U. and Bougie,R., (2010). "Research Methods for Business: A Skill Building Approach." Fifth edition.

Silverman, D. (2006). "Interpreting qualitative data: Methods for analyzing talk text and interaction." Sage, GB.

Sommerville, J., (2007). "Defects and rework in new build: an analysis of the phenomenon and drivers." Structural Survey, 25(5) 391 – 407.

Stewart M. G., (1992). "Simulation of human error in reinforced concrete design" Research in Engineering Design Journal, 4, 51-60.

Tzortzopoulos, P and Formoso, C (1999). "Considerations on application of lean construction principles to design management" Proceeding of IGLC 7 Berkeley, USA

Undurraga, M,. (1996). "Construction productivity and housing financing" Seminar and Workshop Interamerican Housing Union, Ciudad de Mexico, D.E., Mexico, 28-29 October,

Womack, J. P., and Jones, D. T. (1996). "Lean thinking" Simon and Schuster, New York, USA

Yin, K.R., (2009). "Case study research methods" SAGE publications.